Heat Transfer

1. Modes of heat transfer

Heat Transfer by Conduction
Fourier's law of heat conduction
Thermal conductivity of materials

2. One Dimensional Steady Conduction

General Heat Conduction Equation in Cartesian Coordinates
General Heat Conduction Equation in Cylindrical Coordinates
General Heat Conduction Equation in Spherical Coordinates

Heat conduction through a plane wall
Heat conduction through a composite wall
The overall heat transfer coefficient

Heat conduction through a hollow cylinder
Logarithmic mean area for the hollow cylinder
Heat conduction through a composite cylinder

Heat conduction through a hollow sphere
Logarithmic mean area for the hollow sphere
Heat condition through a composite sphere

Critical Thickness of Insulation

Critical thickness of insulation
Heat conduction with Internal Heat Generation
Plane wall with uniform heat generation
Dielectric heating
Cylinder with uniform heat generation
Heat conduction with heat generation in the nuclear cylindrical fuel rod
Sphere with uniform heat generation

3. Heat Transfer from Extended Surfaces (Fins)

Heat flow through "Rectangular fin"
Heat dissipation from an infinitely long fin
Heat dissipation from a fin insulated at the tip
Heat dissipation from a fin losing heat at the tip
Efficiency and effectiveness of fin
Estimation of error in temperature measurement in a thermometer well
Heat transfer from a bar connected to the two heat sources at different, temperatures

4. One Dimensional Unsteady Conduction

Heat Conduction in Solids having Infinite Thermal Conductivity (Negligible internal Resistance-Lumped Parameter Analysis)
Time Constant and Response of -Temperature Measuring Instruments
Transient Heat Conduction in Solids with Finite conduction and Convective Resistances ($0 < H_i < 100$),
Transient. Heat Conduction in Semi-infinite Solids (h or H_i 4.5. 30-5 00),
Systems with Periodic Variation of Surface Temperature
Transient Conduction with Given Temperature Distribution,

5. Free & Forced convection

5. Boiling and Condensation

Boiling Heat Transfer
Boiling regimes
Bubble shape and size consideration
Bubble growth and collapse
Critical diameter of bubble
Factors affecting nucleate boiling
Boiling correlations
Nucleate pool boiling
Critical heat flux for nucleate pool boiling
Film pool boiling

Condensation Heat Transfer
Laminar film condensation on a vertical plate
Turbulent film condensation
Film condensation on horizontal tubes
Film condensation inside horizontal tubes
Influence of the presence of non condensable gases

6. Heat Exchangers

Types of Heat Exchangers, 529
Logarithmic Mean Temperature Difference (LMTD), 535
Overall Heat Transfer Coefficient, 539
Heat Exchanger Effectiveness and Number of Transfer Units (NTU), 582

7. Radiation

Introduction
Absorptivity, Reflectivity and Transmissivity, 629
Black body, 630
The Stefan-Boltzmann Law
Kirchoff's Law, 631
Planck's Law, 632
Wien Displacement Law, 633
Intensity of Radiation and Lambert's Cosine Law, 634
Radiation Exchange between Black Bodies Separates by a Non-absorbing Medium, 641
Shape Factor Algebra and Salient Features of the Shape Factor, 645
Heat Exchange between Non-black Bodies, 661
Electrical Network Analogy for Thermal Radiation Systems, 666
Radiation Shields, 692

8. Mass Transfer

Modes of Mass Transfer. 715
Fick's Law, 718 .

1. Modes of heat transfer

Objective Questions (IES, IAS, GATE)

Heat Transfer by Conduction

1. A copper block and an air mass block having similar dimensions are subjected to symmetrical heat transfer from one face of each block. The other face of the block will be reaching to the same temperature at a rate **[IES-2006]**
(a) Faster in air block (b) faster in copper block
(c) Equal in air as well as copper block
(d) Cannot be predicted with the given information
1. Ans. (b)

Fourier's law of heat conduction

2. Consider the following statements: **[IES-1998]**
The Fourier heat conduction equation $Q = kA\frac{dT}{dx}$ presumes
1. steady-state conditions 2. constant value of thermal conductivity.
3. uniform temperatures at the wall surfaces 4. one-dimensional heat flow.
Of these statements
(a) 1, 2 and 3 are correct (b) 1, 2 and 4 are correct
(c) 2, 3 and 4 are correct (a) 1, 3 and 4 are correct
2. Ans. (b)

3. A plane wall is 25 cm thick with an area of 1 m^2, and has a thermal conductivity of 0.5 W/mK. If a temperature difference of 60°C is imposed across it, what is the heat flow?
(a) 120W (b) 140W (c) 160W (d) 180W **[IES-2005]**
3. Ans. (a) $Q = kA\frac{dT}{dx} = 0.5 \times 1 \times \frac{60}{0.25}\,W = 120\,W$

4. For a given heat flow and for the same thickness, the temperature drop across the material will be maximum for **[GATE-1996]**
(a) copper (b) steel (c) glass-wool (d) refractory brick
4. Ans. (c) $Q = -kA\frac{dT}{dx}$
$\frac{Qdx}{A} = -kdT \quad \therefore kdT = constant \quad or\ dT \propto \frac{1}{k}$
Which one has minimum thermal conductivity that will give maximum temperature drop.

5. Thermal diffusivity of a substance is **[IES-2006]**
(a) Inversely proportional to thermal conductivity
(b) Directly proportional to thermal conductivity
(c) Directly proportional to the square of thermal conductivity
(d) Inversely proportional to the square of thermal conductivity
5. Ans. (b) Thermal diffusivity (α) = $\frac{k}{\rho c_p} \therefore \alpha \propto k$

7. Which one of the following expresses the thermal diffusivity of a substance in terms of thermal conductivity (k), mass density (ρ) and specific heat (c)? **[IES-2006]**
(a) k^2 ρc (b) 1/ ρkc (c) k/ ρ c (d) ρ c/k^2

7. Ans. (c) $\alpha = \frac{k}{\rho c_p}$

8. Match List-I and List-II and select the correct answer using the codes given below the lists: **[IES-2001]**
(h_m - mass transfer coefficient, D - molecular diffusion coefficient,
L - characteristic length dimension, k - thermal conductivity, ρ - density,
C_p - specific heat at constant pressure, μ - dynamic viscosity)

List-I	List-II
A. Schmidt number	1. $\frac{k}{\left(\rho C_p D\right)}$
B. Thermal diffusivity	2. $\frac{h_m L}{D}$
C. Lewis number	3. $\frac{\mu}{\rho D}$
D. Sherwood number	4. $\frac{k}{\rho C_p}$

	A	B	C	D		A	B	C	D
(a)	4	3	2	1	(b)	4	3	1	2
(c)	3	4	2	1	(d)	3	4	1	2

8. Ans. (c)

9. Match List I with List II and select the correct answer **[IES-1996]**

List I	List II
A. Momentum transfer	1. Thermal diffusivity
B. Mass transfer	2. Kinematic viscosity
C. Heat transfer	3. Diffusion coefficient

Codes:	A	B	C		A	B	C
(a)	2	3	1	(b) 1	3	2	
(c)	3	2	1	(d) 1	2	3	

9. Ans. (a)

10. Assertion (A): Thermal diffusivity is a dimensionless quantity. **[IES-1992]**
Reason (R): In M-L-T-Q system the dimensions of thermal diffusivity are I^2T^{-1}
10. Ans. (d)

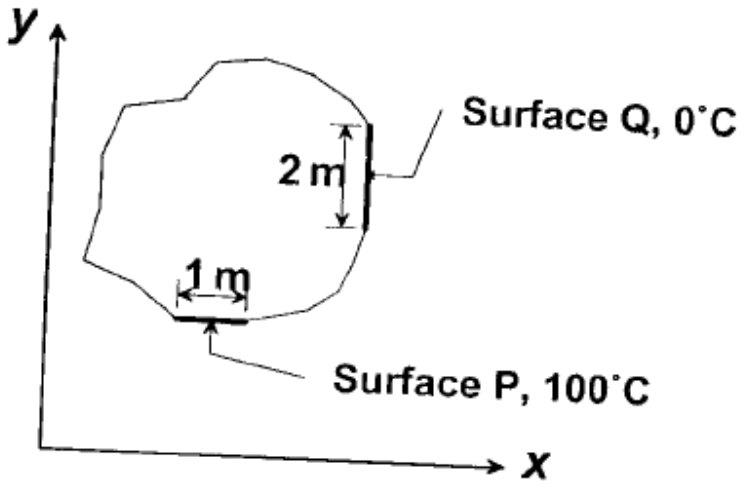
11. A furnace is made of a red brick wall of thickness 0.5 m and conductivity 0.7 W/mK. For the same heat loss and temperature drop, this can be replaced by a layer of diatomite earth of conductivity 0.14 W/mK and thickness **[IES-1993]**
(a) 0.05 m (b) 0.1 m (c) 0.2 m (d) 0.5 m

11. Ans. (b) For thick place homogeneous wall, heat loss = $kA\frac{dt}{dx}$

$$or\left(0.7\times A\times\frac{dt}{0.5}\right)_{red\,brick}=\left(0.14\times A\frac{dt}{dx}\right)_{diatomic}\quad or\Delta x=0.1m$$

12. Steady two-dimensional heat conduction takes place in the body shown in the figure below. The normal temperature gradients over surfaces P and Q can be considered to be

uniform. The temperature gradient $\frac{\partial T}{\partial x}$ at surface Q is equal to 10 *K/m.* Surlaces P an Q are maintained at constant temperatures as shown in the figure, while the remaining part of the boundary is insulated. The body has a constant thermal conductivity of 0.1 W/m.K. The values of $\frac{\partial T}{\partial x} and \frac{\partial T}{\partial y}$ at surface P are **[GATE-2008]**



(A) $\frac{\partial T}{\partial x} = 20K/m, \frac{\partial T}{\partial y} = 0K/m$ (B) $\frac{\partial T}{\partial x} = 0K/m, \frac{\partial T}{\partial y} = 10K/m$

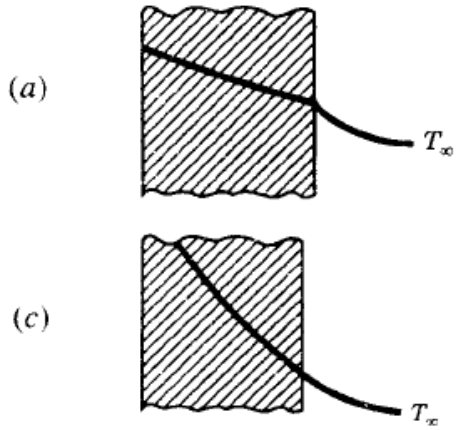
(C) $\frac{\partial T}{\partial x} = 10K/m, \frac{\partial T}{\partial y} = 10K/m$ (D) $\frac{\partial T}{\partial x} = 0K/m, \frac{\partial T}{\partial y} = 20K/m$

12. Ans. (D)

13. Assertion (A): The leakage heat transfer from the outside surface of a steel pipe carrying hot gases is reduced to a greater extent on providing refractory brick lining on the inside of the pipe as compared to that with brick lining on the outside. **[IES-2000]**
Reason (R): The refractory brick lining on the inside of the pipe offers a higher thermal resistance.
13. Ans. (a)

14. Assertion (A): Thermal conductance of heat pipe is several hundred times that of the best available metal conductor under identical conditions. **[IES-2000]**
Reason (R): The value of latent heat is far greater than that of specific heat.
14. Ans. (a)

15. Temperature profiles for four cases are shown in the following figures and are labelled A, B, C and D.



Match the above figures with **[IES-1998]**

1. High conductivity fluid 2. Low conductivity fluid 3. Insulating body 4. Guard heater

Select the correct answer using the codes given below:

Code:	A	B	C	D		A	B	C	D
(a)	1	2	3	4	(b)	2	1	3	4
(c)	1	2	4	3	(d)	2	1	4	3

15. Ans. (a) Temperature slope is higher for low conducting and lower for high conducting fluid. Thus A is for 1, B for 2. Temperature profile in C is for insulator. Temperature rise is possible only for heater and as such D is for guard heater.

16. A steel ball of mass 1kg and specific heat 0.4 kJ/kg is at a temperature of 60°C. It is dropped into 1kg water at 20°C. The final steady state temperature of water is **[GATE-1998]**

(a) 23.5°C (b) 300C (c) 35°C (d) 40°C

16. Ans. (a) Heat loss by hot body = heat gain by cold body

$$m_h c_{ph}(t_h - t_f) = m_c c_{pc}(t_f - t_c)$$

$$\text{or } 1\times 0.4\times(60 - t_f) = 1\times 4.2\times(t_f - 20) \qquad \text{or } t_f = 13.5^\circ C$$

Thermal conductivity of materials

17. In descending order of magnitude, the thermal conductivity of **[GATE-2001]**

a. pure iron
b. liquid water
c. saturated water vapour

and d. pure aluminium can be arranged as

(a) a b c d (b) b c a d (c) d a b c (d) d c b a

17. Ans. (b)

18. Match the following: **[IES-1992]**

List I	List II
(a) Normal boiling point of oxygen	1. 1063°C
(b) Normal boiling point of sulphur	2. 630.5°C
(c) Normal melting point of Antimony	3. 444°C
(d) Normal melting point of Gold	4. -182.97°C

Code:	A	B	C	D		A	B	C	D
(a)	4	2	3	1	(b)	4	3	1	2
(c)	4	2	3	1	(d)	4	3	2	1

18. Ans. (d)

19. Heat pipe is widely used now-a-days because **[IES-1995]**
(a) it acts as an insulator (b) it acts as conductor and insulator
(c) it acts as a superconductor (d) it acts as a fin.
19. Ans. (b) Heat pipe can be used in different ways. Insulated portion may be made of flexible tubing to permit accommodation of different physical constraints. It can also be applied to micro-electronic circuits to maintain constant temperature. It consists of a closed pipe lined with a wicking material and containing a condensable gas. The centre portion of pipe is insulated and its two non-insulated ends respectively serve as evaporators and condensers.

20. Assertion (A): Hydrogen cooling is used for high capacity electrical generators.
Reason (R): Hydrogen is light and has high thermal conductivity as compared to air.
[IES-1992]
20. Ans. (a)

Answers with Explanation (Objective)

2. One Dimensional Steady Conduction

Objective Questions (IES, IAS, GATE)

General Heat Conduction Equation in Cartesian Coordinates

1. In a case of one dimensional heat conduction in a medium with constant properties, T is the temperature at position x, at time t. Then $\frac{\partial T}{\partial t}$ is proportional to **[GATE-2005]**

$(a)\frac{T}{x}$ $(b)\frac{\partial T}{\partial x}$ $(c)\frac{\partial^2 T}{\partial x \partial t}$ $(d)\frac{\partial^2 T}{\partial x^2}$

1. Ans. (d) One dimensional, Unsteady state, without internal heat generation

$$\frac{\partial^2 T}{\partial x^2} = \frac{1}{\alpha}\frac{\partial T}{\partial t}$$

General Heat Conduction Equation in Cylindrical Coordinates

General Heat Conduction Equation in Spherical Coordinates

2. One dimensional unsteady state heat transfer equation for a sphere with heat generation at the rate of 'q' can be written as **[GATE-2004]**

(a) $\frac{1}{r}\frac{\partial}{\partial r}\left(r\frac{\partial T}{\partial r}\right)+\frac{q}{k}=\frac{1}{\alpha}\frac{\partial T}{\partial t}$

(b) $\frac{1}{r^2}\frac{\partial}{\partial r}\left(r^2\frac{\partial T}{\partial r}\right)+\frac{q}{k}=\frac{1}{\alpha}\frac{\partial}{\partial t}$

(c) $\frac{\partial^2 T}{\partial r^2}+\frac{q}{k}=\frac{1}{\alpha}\frac{\partial T}{\partial t}$

(d) $\frac{\partial^2}{\partial r^2}(rT)+\frac{q}{k}=\frac{1}{\alpha}\frac{\partial T}{\partial t}$

2. Ans. (b)

Heat conduction through a plane wall

3. A wall of thickness 0.6 m has width has a normal area 1.5 m^2 and is made up of material of thermal conductivity 0.4 W/mK. The temperatures on the two sides are 800^0 C. What is the thermal resistance of the wall?

(a) 1 W/K (b) 1.8 W/K
(c) 1 K/W (d) 1.8 K/W **[IES 2007]**

3. Ans. (c) $R = \frac{L}{KA} = \frac{0.6}{0.4\times 1.5} = 1\ K/W$

4. A metal plate has a surface area of $2m^2$, thickness 10 mm and a thermal conductivity of 200 W/mk. What is the thermal resistance of the plate? **[IES-2006]**

(a) 4×10^4 K/W (b) 2.5×10^{-3} K/W (c) 1.5×10^{-5} K/W (d) 2.5×10^{-5} K/W

4. Ans. (d) Thermal resistance (R) = $\frac{L}{KA}=\frac{0.010}{200\times 2}=2.5\times 10^{-5}\ K/W$

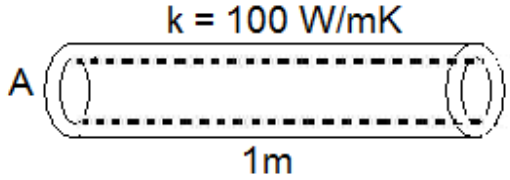
5. Heat is conducted through a 10 cm thick wall at the rate of 30 W/m^2 when the temperature difference across the wall is 10^0C. What is the thermal conductivity of the wall?

(a) 0.03 W/mK (b) 0.3 W/mK (c) 3.0 W/mK (d) 30.0 W/mK **[IES-2005]**

5. Ans. (b) $\dot{q} = K\frac{dT}{dx}$ or $k=\frac{\dot{q}}{\left(\frac{dT}{dx}\right)}=\frac{30}{\left(\frac{10}{0.1}\right)}=0.3\ W/mK$

6. A 0.5 m thick plane wall has its two surfaces kept at 300°C and 200°C. Thermal conductivity of the wall varies linearly with temperature and its values at 300 °C and 200 °C are 25 W/mK and 15W/mK respectively. Then the steady heat flux through the wall is.
(a) 8 kW/m^2 (b) 5 kW/m^2 (c) 4kW/m^2 (d) 3 kW/m^2 **[IES-2002]**
6. Ans. (c)

7. 6.0 kJ of conduction heat transfer has to take place in 10 minutes from one end to other end of a metallic cylinder of 10 cm^2 cross-sectional area, length 1 meter and thermal conductivity as 100 W/mK. What is the temperature difference between the two ends of the cylindrical bar? **[IES-2005]**
(a) 80°C (b) 100°C (c) 120°C (d) 160°C
7. Ans. (b)



$$\therefore \dot{Q} = kA\frac{dT}{dx}$$

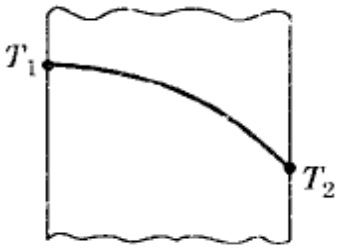
$$\text{or} \quad \frac{6000}{10\times 60} = 100\times\left(\frac{10}{10000}\right)\times\frac{dT}{1}$$

$$\text{or} \quad dT = 100^0 C$$

8. In a large plate, the steady temperature distribution is as shown in the given figure. If no heat is generated in the plate, the thermal conductivity 'k' will vary T as (T is temperature and α is a constant)

$(a)\, k_o(1+\alpha T)$ $(b)\, k_o(1-\alpha T)$

$(c)\, 1+\alpha T$ $(d)\, 1-\alpha T$

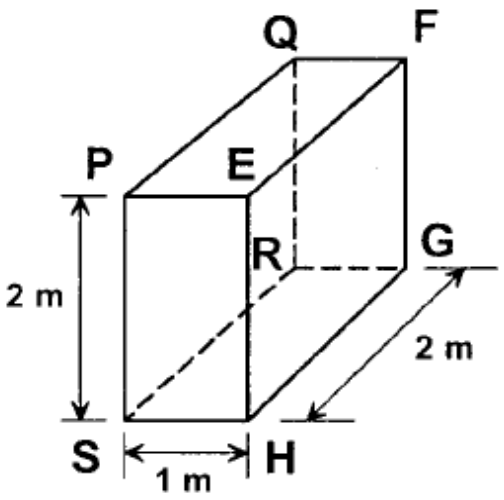


[IES-1997]

8. Ans. (a) For the shape of temperature profile. K = $k_o(1+\alpha T)$

9. A building has to be maintained at 21°C (dry bulb) and 14.5°C. The outside temperature is -23°C (dry bulb) and the internal and external surface heat transfer coefficients are 8 W/m^2K and 23 W/m^2K respectively. If the building wall has a thermal conductivity of 1.2 W/mK, the minimum thickness (in m) of the wall required to prevent condensation is
(a) 0.471 (b) 0.407 (c) 0.321 (d) 0.125 **[GATE-2007]**
9. Ans. (b)

10. For the three-dimensional object shown in the figure below, five faces are insulated. The sixth face (PQRS), which is not insulated, interacts thermally with the ambient, with a convective heat transfer coefficient of 10 W /m^2.K. The ambient temperature is 30^0C . Heat is uniformly generated inside the object at the rate of 100 W/m^3. Assuming the face PQRS to be at uniform temperature, its steady state temperature is **[GATE-2008]**


Q
F
P
E
R
G
2 m
2 m
S
1 m
H

(A) 10^0C (B) 20^0C (C) 30^0C (D) 40^0C

10. Ans. (D)

11. The temperature distribution, at a certain instant of time in a concrete slab during curing is given by $T = 3x^2 + 3x + 16$, where x is in cm and T is in K. The rate of change of temperature with time is given by (assume diffusivity to be 0.0003 cm^2/s). **[IES-1994]**

(a) + 0.0009 K/s (b) + 0.0048 K/s (c) - 0.0012 K/s (d) - 0.0018 K/s

11. Ans. (d) Temperature distribution is $T= 3x^2 + 3x + 16$, $dT/dx = 6x + 3$ °K/cm^2

Rate of change of is $dT/dx = 6°$ K/cm^2, :. Rate of change of temperature with time = - 6 x 0.0003 = - 0.0018 °K/s.

Heat conduction through a composite wall

12. A composite wall having three layers of thickness 0.3 m, 0.2 m and 0.1 m and of thermal conductivities 0.6, 0.4 and 0.1 W/mK, respectively, is having surface area 1 m^2. If the inner and outer temperatures of the composite wall are 1840 K and 340 K, respectively, what is the rate of heat transfer?

(a) 150 W (b) 1500 W

(c) 75 W (d) 750 W **[IES 2007]**

12. Ans. (d) $Q = \dfrac{t_f - t_i}{\sum \dfrac{L}{KA}} = \dfrac{1840 - 340}{\dfrac{0.3}{0.6\times1} + \dfrac{0.2}{0.4\times1} + \dfrac{0.1}{0.1\times1}} = 750$ W

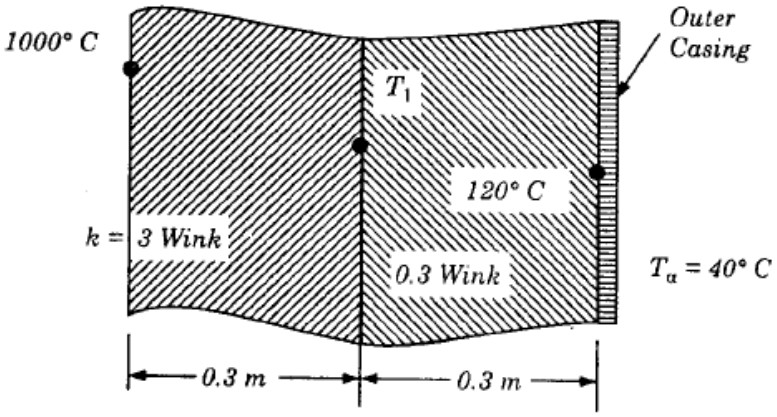
13. A furnace wall is constructed as shown in the given figure. The heat transfer coefficient across the outer casing will be

(a) 80W/m^2K

(b) 40W/m^2K

(c) 20W/m^2K

(d) 10W/m^2K



[IES-1999]

13. Ans. (d) For two insulating layers,

$$\frac{Q}{A} = \frac{t_1 - t_2}{\frac{\Delta x_1}{k_1} + \frac{\Delta x_2}{k_2}} = \frac{1000 - 120}{\frac{0.3}{3} + \frac{0.3}{0.3}} = \frac{880}{1.1} = 800$$

For outer casing, $\frac{Q}{A} = \frac{120\text{-}40}{1/h}$, or $800 \times \frac{1}{h}$, and $h = \frac{800}{80} = 10$ W/m^2K

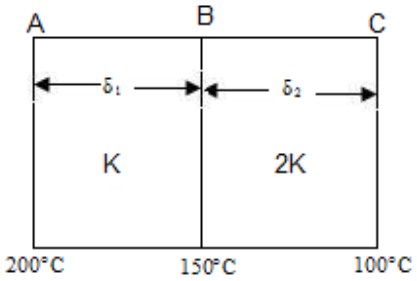
14. A composite wall is made of two layers of thickness σ_1 and σ_2 having thermal conductivities K and 2K and equal surface areas normal to the direction of heat flow. The outer surfaces of the composite wall are at 100°C and 200°C respectively. The heat

transfer takes place only by conduction and the required surface temperature at the junction is 150°C **[IES-2004]**

What will be the ratio of their thicknesses, σ_1: σ_2?

(a) 1: 1 (b) 2 : 1 (c) 1: 2 (d) 2 : 3

14. Ans. (c)



$Q_{AB} = Q_{BC}$

or $-k.A.\left(\frac{200-150}{\delta_1}\right) = -2kA\left(\frac{150-100}{\delta_2}\right)$

or $\frac{\delta_1}{\delta_2} = \frac{50}{2\times 50} = \frac{1}{2}$

15. A composite plane wall is made up of two different materials of the same thickness and having thermal conductivities of k_1 and k_2 respectively. The equivalent thermal conductivity of the slab is **[IES-2000]**

$(a)\, k_1 + k_2 \qquad (b)\, k_1 k_2 \qquad (c)\, \frac{k_1 + k_2}{k_1 k_2} \qquad (d)\, \frac{2k_1 k_2}{k_1 + k_2}$

15. Ans. (c)

16. A composite wall consists of two layers of different materials having conductivities k_1 and k_2 For equal thickness of the two layers, the equivalent thermal conductivity of the slab will be

$(a)\, k_1 + k_2 \qquad (b)\, k_1 k_2 \qquad (c)\, \frac{2k_1 k_2}{k_1 + k_2} \qquad (d)\, \frac{k_1 + k_2}{k_1 k_2}$ **[IES-1997]**

16. Ans. (c) Equivalent thermal conductivity of two layers is equal to $\frac{2k_1 k_2}{k_1 + k_2}$

17. A composite slab has two layers of different materials with thermal conductivity K_1 and K_2. If each layer had the same thickness, the equivalent thermal conductivity of the slab would be

$(a)\, K_1 + K_2 \qquad (b)\, \frac{K_1 + K_2}{K_1 K_2} \qquad (c)\, \frac{2K_1 K_2}{K_1 + K_2} \qquad (d)\, K_1 K_2$ **[IES-1993]**

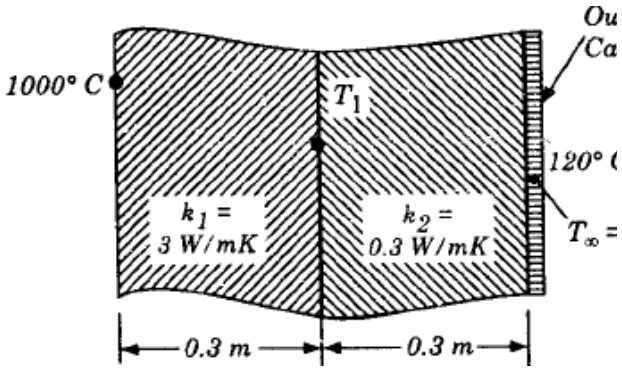
17. Ans. (b)

18. A composite slab has two layers of different materials with thermal conductivity k_1 and k_2 each layer has same thickness, the equivalent thermal conductivity of the slab would be **[IES-1992]**

(a) k_1k_2 (b) k_1/k_2 (c) $(k_1 + k_2)$ (d) $(2k_1k_2 + k_2)$

18. Ans. (d)

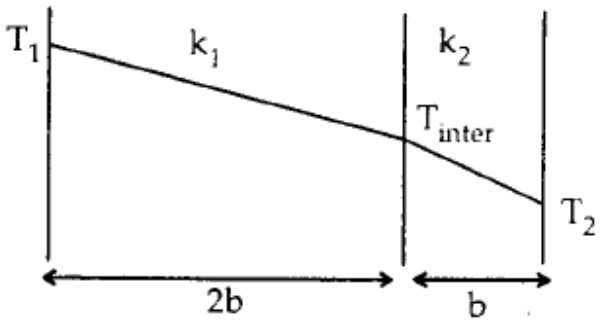
19. A furnace wall is constructed as shown in the above figure. The interface temperature Ti will be
(a) 560°C
(b) 200 °C
(c) 920 °C
(d) 1120 °C



19. Ans. (c) For two insulating layers, $\frac{Q}{A}=\frac{t_1-t_2}{\frac{\Delta x_1}{k_1}+\frac{\Delta x_2}{k_2}}=\frac{1000-120}{\frac{0.3}{3}+\frac{0.3}{0.3}}=800$

Considering first layer, $\frac{Q}{A}=\frac{1000\text{-}T_1}{\frac{0.3}{3}}=800, \text{Or } T_1=1000\text{-}80=920^\circ C$

20. In a composite slab, the temperature at the interface (T_{inter}) between two materials is equal to the average of the temperatures at the two ends. Assuming steady one-dimensional heat conduction, which of the following statements is true about the respective thermal conductivities?



[GATE-2006]

(a) $2k_1 = k_2$ (b) $k_1 = k_2$ (c) $2k_1 = 3k_2$ (d) $k_1 = 2k_2$

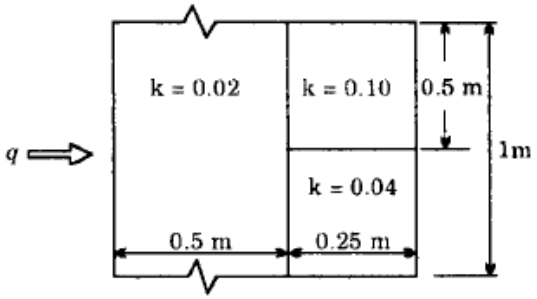
20. Ans. (d)

$$T_{inter}=\frac{T_1+T_2}{2}$$

Heat flow must be same $(Q)=-k_1A\frac{\left(T_1-\frac{T_1+T_2}{2}\right)}{2b}=-k_2\frac{\left(\frac{T_1+T_2}{2}-T_2\right)}{b}$

or $k_1 = 2k_2$

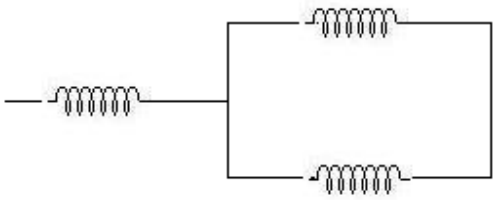
21. Heat flows through a composite slab, as shown below. The depth of the slab is 1 m. The k values are in W/mK. the overall thermal resistance in K/W is
(a) 17.2
(c) 28.6



[GATE-2005]

21. Ans. (c)

Electrical circuit



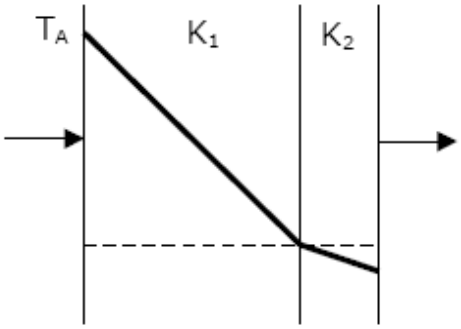
Use this formula

$$R_{eq} = \frac{L_1}{K_1 A_1} + \frac{1}{\frac{1}{\frac{L_2}{K_2 A_2}} + \frac{1}{\frac{L_3}{K_3 A_3}}}$$

22. The temperature variation under steady heat conduction across a composite slab of two materials with thermal conductivities K_1 and K_2 is shown in figure. Then, which one of the following statements holds?

$(a)\ K_1 > K_2$ $(b)\ K_1 = K_2$

$(c)\ K_1 = 0$ $(d)\ K_1 < K_2$



[GATE-1998]

22. Ans. (a) $Q \propto K\frac{dT}{dx}$ as $Q = \text{constant}$. $\frac{dT}{dx} \propto \frac{1}{k}$

$\frac{dT}{dx_1} = \frac{\text{const.}}{k_1}$, $\frac{dT}{dx_2} = \frac{\text{const.}}{k_2}$

$\frac{dT}{dx_1} < \frac{dT}{dx_2}$ or $k_1 > k_2$

The overall heat transfer coefficient

23. A flat plate has thickness 5 cm, thermal conductivity 1W/(mK), convective heat transfer coefficients on its two flat faces of 10 W/(m^2K) and 20W/(m^2K). The overall heat transfer co-efficient for such a flat plate is **[IES-2001]**

(a) 5 W/(m^2K) (b) 6.33 W/(m^2K) (c) 20 W/(m^2K) (d) 30 W/(m^2K)

23. Ans. (a)

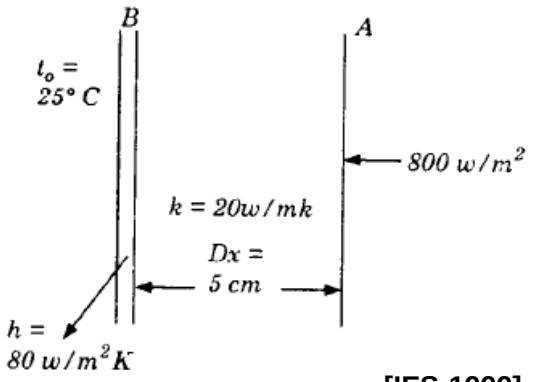
24. The overall heat transfer coefficient U for a plane composite wall of n layers is given by (the thickness of the i^{th} layer is t_i, thermal conductivity of the ith layer is k_i, convective heat transfer coefficient is h) **[IES-2000]**

$(a)\ \frac{1}{\frac{1}{h_1} + \sum_{i=1}^{n}\frac{t_i}{k_i} + \frac{1}{h_n}}$ $(b)\ h_1 + \sum_{i=1}^{n}\frac{t_i}{k_i} + h_n$ $(c)\ \frac{1}{h_1 + \sum_{i=1}^{n}\frac{t_i}{k_i} + h_n}$ $(d)\ \frac{1}{h_1} + \sum_{i=1}^{n}\frac{t_i}{k_i} + \frac{1}{h_n}$

24. Ans. (a)

25. A steel plate of thickness 5 cm and thermal conductivity 20 W/mK is subjected to a uniform heat flux of 800 W/m^2 on one surface 'A' and transfers heat by convection with a heat transfer co-efficient of 80 W/m^{2}K from the other surface 'B' into ambient air T_α of 25°C. The temperature of the surface 'B' transferring heat by convection is

(a) 25°C (b) 35°C
(c) 45°C (d) 55°C



[IES-1999]

25. Ans. (b) $800 = \frac{t_B - t_o}{1/h} = \frac{t_B - 25}{1/80}$

Heat conduction through a hollow cylinder

Logarithmic mean area for the hollow cylinder

26. The heat flow equation through a cylinder of inner radius 'r_1' and outer radius 'r_2' is desired in the same form as that for heat flow through a plane wall. The equivalent area A_m is given by

(a) $\frac{A_1+A_2}{\log_e\left(\frac{A_2}{A_1}\right)}$ (b) $\frac{A_1+A_2}{2\log_e\left(\frac{A_2}{A_1}\right)}$ (c) $\frac{A_2-A_1}{2\log_e\left(\frac{A_2}{A_1}\right)}$ (d) $\frac{A_2-A_1}{\log_e\left(\frac{A_2}{A_1}\right)}$ **[IES-1999]**

26. Ans. (d)

27. The outer surface of a long cylinder is maintained at constant temperature. The cylinder does not have any heat source **[IES-2000]**
The temperature in the cylinder will

(a) increase linearly with radius (b) decrease linearly with radius
(c) be independent of radius (d) vary logarithmically with radius

27. Ans. (c)

Heat conduction through a composite cylinder

28. The heat flow through a composite cylinder is given by the equation: (symbols have the usual meaning) **[IES-1995]**

$(a)\ Q = \frac{(T_1 - T_{n+1})2\pi L}{\sum_{n=1}^{n=n} \frac{1}{K_n} \log_e\left(\frac{r_{n+1}}{r_n}\right)}$ $(b)\ Q = \frac{4\pi(T_1 - T_{n+1})}{\sum_{n=1}^{n=n}\left[\frac{r_{n+1} - r_n}{K_n r_n r_{n+1}}\right]}$ $(c) Q = \frac{T_1 - T_{n+1}}{\frac{1}{A}\sum_{n=1}^{n=n}\left(\frac{L_n}{K_n}\right)}$ $(d) Q = \frac{T_1 - T_2}{\frac{\log_e\left(\frac{r_2}{r_1}\right)}{2\pi KL}}$

28. Ans. (a)

29. A stainless steel tub (k_s = 19 W/mK) of 2 cm ID and 5 cm OD is insulated with 3 cm thick asbestos (k_a = 0.2 W/mK). If the temperature difference between the innermost and outermost surfaces is 600°C, the heat transfer rate per unit length is **[GATE-2004]**
(a) 0.94 W/m (b) 9.44 W/m (c) 944.72 W/m (d) 9447.21 W/m

29. Ans. (c) $$Q = \frac{2\pi L(t_i - t_f)}{\frac{\ln\left(\frac{r_2}{r_1}\right)}{K_A} + \frac{\ln\left(\frac{r_3}{r_2}\right)}{K_B}} = \frac{2\pi \times 1 \times (600)}{\frac{\ln\left(\frac{0.025}{0.01}\right)}{19} + \frac{\ln\left(\frac{0.055}{0.025}\right)}{0.2}} = 944.72\,W/m$$

30. Two insulating materials of thermal conductivity K and 2K are available for lagging a pipe carrying a hot fluid. If the radial thickness of each material is the same.
(a) material with higher thermal conductivity should be used for the inner layer and one with lower thermal conductivity for the outer. **[GATE-1994]**
(b) material with lower thermal conductivity should be used for the inner layer and one with higher thermal conductivity for the outer.
(c) it is immaterial in which sequence the insulating materials are used.
(d) it is not possible to judge unless numerical values of dimensions are given.
30. Ans. (b)

Heat conduction through a hollow sphere

31. For conduction through a spherical wall with constant thermal conductivity and with inner side temperature greater than outer wall temperature, (one dimensional heat transfer), what is the type of temperature distribution?
(a) Linear (b) Parabolic
(c) Hyperbolic (d) None of the above **[IES 2007]**

31. Ans. (c)Temp distribution would be $$\frac{t - t_1}{t_2 - t_1} = \frac{\frac{1}{r} - \frac{1}{r_1}}{\frac{1}{r_2} - \frac{1}{r_1}}$$

32. What is the expression for the thermal conduction resistance to heat transfer through a hollow sphere of inner radius r_1 and outer radius r_2, and thermal conductivity k?
(a) $\frac{(r_2 - r_1)r_1 r_2}{4\pi k}$ (b) $\frac{4\pi k(r_2 - r_1)}{r_1 r_2}$
(c) $\frac{r_2 - r_1}{4\pi k r_1 r_2}$ (d) None of the above **[IES 2007]**

32. Ans. (c) Resistance (R) = $\frac{r_2 - r_1}{4\pi k(r_1 r_2)}$ $\because Q = \frac{\Delta t}{R} = \frac{4\pi k(t_1 - t_2)}{\left(\frac{r_2 - r_1}{r_1 r_2}\right)}$

33. A solid sphere and a hollow sphere of the same material and size are heated to the same temperature and allowed to cool in the same surroundings. If the temperature difference between the body and that of the surroundings is T, then **[IES-1992]**
(a) both spheres will cool at the same rate for small values of T
(b) both spheres will cool at the same reactor small values of T

(c) the hollow sphere will cool at a faster rate for all the values of T
(d) the solid sphere will cool a faster rate for all the values of T
33. Ans. (a)

Logarithmic mean area for the hollow sphere

34. What will be the geometric radius of heat transfer for a hollow sphere of inner and outer radii r_1 and r_2? **[IES-2004]**

(a) $\sqrt{r_1 r_2}$ (b) $r_2 r_1$ (c) r_2 / r_1 (d) $(r_2 - r_1)$

34. Ans. (a)

35. A hollow sphere has inner and outer surface areas of 2 m^2 and 8 m^2 respectively. For a given temperature difference across the surfaces, the heat flow is to be calculated considering the material of the sphere as a plane wall of the same thickness. What is the equivalent mean area normal to the direction of heat flow? **[IAS-2007]**

(a) 6 m^2 (b) 5 m^2 (c) 4 m^2 (d) None of the above

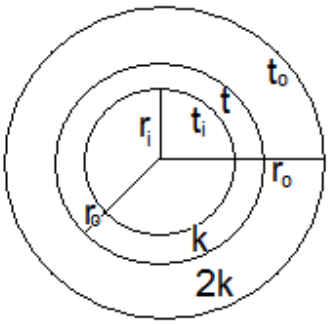
35. Ans. (c) $A_m = \sqrt{A_1 A_2} = \sqrt{2 \times 8} = 4m^2$

Heat condition through a composite sphere

35. A composite hollow sphere with steady internal heating is made of 2 layers of materials of equal thickness with thermal conductivities in the ratio of 1: 2 for inner to outer layers. Ratio of inside to outside diameter is 0.8. What is ratio of temperature drop across the inner and outer layers? **[IES-2005]**

(a) 0.4 (b) 1.6 (c) 2 ln (0.8) (d) 2.5

35. Ans. (d)



$r_i = 0.8\, r_o$ and $r = r_i + t = r_2 - t$

or $2r = r_i + r_o$ $\quad r = \dfrac{r_i + r_o}{2}$

$r = \dfrac{r_i + 1.25 r_i}{2} = 1.125 r_i$

$r = \dfrac{0.8 r_o + r_o}{2} = 0.9 r_o$ or $\dfrac{r_0}{r} = \dfrac{1}{0.9}$

$$Q = \frac{ti - t}{\dfrac{\ln\left(\dfrac{r}{r_1}\right)}{2\pi k L}} = \frac{t - t_o}{\dfrac{\ln\left(\dfrac{r_o}{r}\right)}{2\pi (2k) L}}$$

or $\dfrac{t_i - t}{t - t_o} = 2 \times \dfrac{\ln(r / r_i)}{\ln(r_o / r)} = 2 \times \dfrac{\ln(1.125)}{\ln\left(\dfrac{1}{0.9}\right)} = 2.24$

36. Match List I (Governing Equations of Heat Transfer) with List II (Specific Cases of Heat Transfer) and select the correct answer using the code given below: **[IES-2005]**

	List I	List II
A.	$\frac{d^2T}{dr^2}+\frac{2}{r}\frac{dT}{dr}=0$	1. Pin fin 1-D case
B.	$\frac{\partial^2T}{\partial x^2}=\frac{1}{\alpha}\frac{\partial T}{\partial t}$	2. 1-D conduction in cylinder
C.	$\frac{d^2T}{dr^2}+\frac{1}{r}\frac{dT}{dr}=0$	3. 1-D conduction in sphere
D.	$\frac{d^2\theta}{dx^2}-m^2\theta=0$	4. Plane slab

(Symbols have their usual meaning)

	A	B	C	D		A	B	C	D
(a)	2	4	3	1	(b)	3	1	2	4
(c)	2	1	3	4	(d)	3	4	2	1

36. Ans. (d)

Answers with Explanation (Objective)

Critical Thickness of Insulation

Objective Questions (IES, IAS, GATE)

Critical thickness of insulation

1. Upto the critical radius of insulation: **[IES-2005]**
(a) Added insulation increases heat loss
(b) Added insulation decreases heat loss
(c) Convection heat loss is less than conduction heat loss
(d) Heat flux decreases
1. Ans. (a)

2. A hollow pipe of 1 cm outer diameter is to be insulated by thick cylindrical insulation having thermal conductivity 1 W/mK. The surface heat transfer coefficient on the insulation surface is 5 W/m^{2}K. What is the minimum effective thickness of insulation for causing the reduction in heat leakage from the insulated pipe? **[IES-2004]**
(a) 10 cm (b) 15 cm (b) 195 cm (d) 20 cm

2. Ans. (c) critical radius of insulation $(r_c) = \frac{k}{h} = \frac{1}{5} = 0.2m = 20cm$

$\therefore$ Critical thickness of insulation $(\Delta r)_C = r_c - r_1 = 20 - 0.5 = 19.5cm$

3. A metal rod of 2 cm diameter has a conductivity of 40W/mK, which is to be insulated with an insulating material of conductivity of 0.1 W/m K. If the convective heat transfer coefficient with the ambient atmosphere is 5 W/m^{2}K, the critical thickness of insulation will be **[IES-2003]**
(a) 1cm (b) 2 cm (c) 7 cm (d) 8 cm
3. Ans. (a)

$$\text{critical radius of insulation}(r_c) = \frac{K}{h} = \frac{0.1}{5} = 0.02\,m = 2\,cm$$

$$\text{critical thickness of insulation}(t) = r_c - r_1 = 2 - 1 = 1\,cm$$

4. A cylinder made of a metal of conductivity 40 W/(mK) is to be insulated with a material of conductivity 0.1 W/(mK). If the convective heat transfer coefficient with the ambient atmosphere is 5W /(m^{2}K), the critical radius of insulation is **[IES-2001]**
(a) 2 cm (b) 4 cm (c) 8 cm (d) 50 cm
4. Ans. (a)

5. A copper wire of radius 0.5 mm is insulated with a sheathing of thickness 1 mm having a thermal conductivity of 0.5 W/m - K. The outside surface convective heat transfer coefficient is l0 W/m^2 - K. If the thickness of insulation sheathing is raised by 10 mm, then the electrical current-carrying capacity of the wire will **[IES-2000]**
(a) increase (b) decrease
(c) remain the same (d) vary depending upon the electrical conductivity of the wire
5. Ans. (c)

6. It is desired to increase the heat dissipation rate over the surface of an electronic device of spherical shape of 5 mm radius exposed to convection with h = 10W/m^2k by encasing it in a spherical sheath of conductivity 0.04 W/mk, For maximum heat flow, the diameter of the sheath should be **[IES-1996]**

(a) 18mm (b) 16mm (c) 12mm (d) 8 mm,

6. Ans. (b) The critical radius of insulation for ensuring maximum heat transfer by conduction = $\frac{2k}{h} = \frac{2 \times 0.04}{10} m = 8 mm$ Therefore diameter should be 16 mm.

7. Assertion (A): Addition of insulation to the inside surface of a pipe always reduces heat transfer rate and critical radius concept has no significance. **[IES-1995]**

Reason (R): If insulation is added to the inside surface, both surface resistance and internal resistance increase.

7. Ans. (a) A and R are correct. R is right reason for A.

8. Match List I with List II and select the correct answer using the codes given below the lists:

List I (Parameter)	List II (Definition)
A. Time constant of a thermometer of radius r_o	1. hr/kfluid
B. Biot number for a sphere of radius r_o	2. klh
C. Critical thickness of insulation for a wire of radius r_o	3. hr/kw1id
D. Nusselt number for a sphere of radius r_o	4. h21trol/peV

[IES-1995]

Nomenclature :- h : film heat transfer coefficient, k : thermal conductivity of solid k_{fluid} : thermal conductivity of fluid, ρ : density, c : specific heat, V: volume, *l* : length.

Codes:	A	B	C	D		A	B	C	D
(a)	4	3	2	1	(b)	1	2	3	4
(c)	2	3	4	1	(d)	4	1	2	3

8. Ans. (a)

9. In current carrying conductors, if the radius of the conductor is less than the critical radius, then addition of electrical insulation is desirable, as **[IES-1995]**

(a) it reduces the heat loss from the conductor and thereby enables the conductor to carry a higher current.

(b) it increases the heat loss from the conductor and thereby enables the conductor to carry a higher current.

(c) it increases the thermal resistance of the insulation and thereby enables the conductor to carry a higher current.

(d) it reduces the thermal resistance of the insulation and thereby enables the conductor to carry a higher current.

9. Ans. (a)

10. Upto the critical radius of insulation **[IES-1993]**

(a) added insulation will increase heat loss (b) added insulation will decrease heat loss

(c) convection heat loss will be less than conduction heat loss

(d) heat flux will decrease

10. Ans. (b) Upto the critical radius of insulation, the added insulation will decrease heat loss and will have no effect beyond that.

11. An electric cable of aluminium conductor (k = 240w/mk) is to be insulated with rubber (k+0.15 w/mk). The cable is to be located in air (h = 6ω/m^2). The critical thickness of insulation will be **[IES-1992]**

(a) 25mm (b) 40 mm (c) 160 mm (d) 800 mm

11. Ans. (a)

104. Critical thickness of insulation $= \frac{k \text{ (thermal conductivity of insulation)}}{h \text{ (convective heat transfer coefficient)}}$

$$= \frac{0.15}{6} = 0.025 \text{ m} i.e. 25 \text{ mm}$$

12. In order to substantially reduce leakage of heat from atmosphere into cold refrigerant flowing in small diameter copper tubes in a refrigerant system, the radial thickness of insulation, cylindrically wrapped around the tubes, must be **[IAS-2007]**

(a) Higher than critical radius of insulation

(b) Slightly lower than critical radius of insulation

(c) Equal to the critical radius of insulation

(d) Considerably higher than critical radius of insulation

12. Ans. (d) At critical radius of insulation heat leakage is maximum if we add more insulation then heat leakage will reduce.

13. A copper pipe carrying refrigerant at - 200 C is covered by cylindrical insulation of thermal conductivity 0.5 W/m K. The surface heat transfer coefficient over the insulation is 50 W/m^2 K. The critical thickness of the insulation would be **[IAS-2001]**

(a) 0.01 m (b) 0.02 m (c) 0.1 m (d) 0.15 m

13. Ans. (a) Critical radius of insulation $\left(r_c\right) = \frac{k}{h} = \frac{0.5}{50} m = 0.01 \text{m}$

14. A steel steam pipe 10 cm inner diameter and 11 cm outer diameter is covered with insulation having the thermal conductivity of 1 W/mK. If the convective heat transfer coefficient between the surface of insulation and the surrounding air is 8 W / m^2K, then critical radius of insulation is

(d) 10 cm (b) 11 cm (c) 12.5 cm (d) 15 cm **[GATE-2000]**

14. Ans. (c) Critical radius of insulation (r_c) = $\frac{k}{h} = \frac{1}{8} \text{m} = 12.5 \text{cm}$

15. It is proposed to coat a 1 mm diameter wire with enamel paint (k = 0.1 W/mK) to increase heat transfer with air. If the air side heat transfer coefficient is 100 W/m^2K, then optimum thickness of enamel paint should be **[GATE-1999]**

(a) 0.25 mm (b) 0.5 mm (c) 1mm (d) 2 mm

15. Ans. (b) Critical radius of insulation (r_c) = $\frac{k}{h} = \frac{0.1}{100} \text{m} = 1 \text{mm}$

$$\therefore \text{Critical thickness of enamel point} = r_c - r_i = 1 - \frac{1}{2} = 0.5 \text{ mm}$$

16. For a current wire of 20 mm diameter exposed to air (h = 20 W/m^2K), maximum heat dissipation occurs when thickness of insulation (k = 0.5 W/mK) is **[GATE-1996]**

(a) 20 mm (b) 25 mm (c) 20 mm (d) 10 mm

16. Ans. (b) Maximum heat dissipation occurs when thickness of insulation is critical.

Critical radius of insulation $\left(r_c\right) = \frac{k}{h} = \frac{0.5}{20} \text{m} = 25 \text{ mm}$

Therefore thickness of insulation = $r_c - r_i = 25 - \frac{20}{2} = 15$ mm

17. For a current carrying wire of 20 mm diameter exposed to air (h = 25W/m^{2}K), maximum heat distribution occurs when the thickness of insulation (k = 0.5 W/m K), is
(a) 20 mm (b) 10 mm (c) 2.5 mm (d) 0 mm **[GATE-1993]**
17. Ans. (b)

$$\text{Critical thickness of insulation} = \frac{k}{h} = \frac{0.5 \text{ W/mK}}{25 \text{ W/m}^2\text{K}}$$

$$= \frac{1}{50} \text{ m} = 20 \text{ mm}$$

$$\text{Thickness of insulation} = 20 - 10 = \mathbf{10 \text{ mm}}$$

18. Consider the following statements: **[IES-1996]**
1. Under certain conditions, an increase in thickness of insulation may increase the heat loss from a heated pipe.
2. The heat loss from an insulated pipe reaches a maximum when the outside radius of insulation is equal to the ratio of thermal conductivity to the surface coefficient.
3. Small diameter tubes are invariably insulated.
4. Economic insulation is based on minimum heat loss from pipe.

Of these statements
(a) 1 and 3 are correct (b) 2 and 4 are correct (c) 1 and 2 are correct (d) 3 and 4 are correct.
18. Ans. (c)

19. A steam pipe is covered with two layers of insulating materials, with the better insulating material forming the outer part. If the two layers are interchanged, the heat conducted **[IES-1997]**
(a) will decrease (b) will increase (c) will remain unaffected
(d) may increase or decrease depending upon the thickness of each layer
19. Ans. (c) Heat conducted will remain unaffected irrespective of how insulating materials are placed. However in practice, better material is placed near hot surface.

20. A steam pipe is to be lined with two layers of insulating materials of different thermal conductivities. For minimum heat transfer **[IES-1994]**
(a) the better insulation must be put inside (b) the better insulation must be put outside
(c) one could place either insulation on either side
(d) one should take into account the steam temperature before deciding as to which insulation is put where.
20. Ans. (a) For minimum heat transfer, the better insulation must be put inside.

21. A steam pipe of 10 cm outside diameter is covered with layers of insulating material each 25 mm thick, one having conductivity k_a which is three times the conductivity k_b of the other material. It can be concluded that the effective conductivity of the two layers
(a) will be less when better insulating material is on inside **[IES-1992]**
(b) will be when better insulating material is on outside
(c) will be least affected when a material is inside and the other outside of vice-versa.
(d) none of the above

21. Ans. (a)

Heat conduction with Internal Heat Generation

22. Water jacketed copper rod "D" m in diameter is used to carry the current. The water, which flows continuously maintains the rod temperature at $T_i^O C$ during normal operation at "I" amps. The electrical resistance of the rod is known to be "R" Ω/m. If the coolant water ceased to be available and the heat removal diminished greatly, the rod would eventually melt. What is the time required for melting to occur if the melting point of the rod material is T_{mp}? [Cp = specific heat, ρ = density of the rod material and L is the length of the rod] **[IES-1995]**

$(a)\frac{\rho(\pi D^2/4)C_p(T_{mp}-T_i)}{I^2R}$ $(b)\frac{(T_{mp}-T_i)}{\rho I^2R}$ $(c)\frac{\rho(T_{mp}-T_i)}{I^2}$ $(d)\frac{C_p(T_{mp}-T_i)}{I^2R}$

22. Ans. (a)

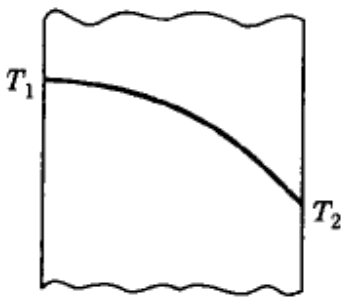
Plane wall with uniform heat generation

23. A plane wall of thickness 2L has a uniform volumetric heat source q* (W/m^3). It is exposed to local ambient temperature T_∞ at both the ends (x = ± L). The surface temperature T_s of the wall under steady-state condition (where hand k have their usual meanings) is given by **[IES-2001]**

(a) $T_s = T_\infty + \frac{q^* L}{h}$ (b) $T_s = T_\infty + \frac{q^* L^2}{2k}$ c) $T_s = T_\infty + \frac{q^* L^2}{h}$ (d) $T_s = T_\infty + \frac{q^* L^3}{2k}$

23. Ans. (a)

24. The temperature variation in a large plate, as shown in the given figure, would correspond to which of the following condition (s)?



1. Unsteady heat 2. Steady-state with variation of k
3. Steady-state with heat generation.

Select the correct answer using the codes given below:

Codes: (a) 2 alone (b) 1 and 2
(c) 1 and 3 (d) 1, 2 and 3

[IES-1998]

24. Ans. (a)

25. In a long cylindrical rod of radius R and a surface heat flux of q_o the uniform internal heat generation rate is

$(a)\frac{2q_0}{R}$ $(b)\,2q_0$ $(c)\frac{q_0}{R}$ $(d)\frac{q_0}{R^2}$ **[IES-1998]**

25. Ans. (c)

Dielectric heating

Cylinder with uniform heat generation

Heat conduction with heat generation in the nuclear cylindrical fuel rod

26. Two rods, one of length L and the other of length 2L are made of the same material and have the same diameter. The two ends of the longer rod are maintained at 100°C. One end of the shorter rod Is maintained at 100°C while the other end is insulated. Both the rods are exposed to the same environment at 40°C. The temperature at the insulated end of the shorter rod is measured to be 55°C. The temperature at the mid-point of the longer rod would be **[GATE-1992]**

(a) 40°C (b) 50°C (c) 55°C (d) 100°C

26. Ans. (C)

Sphere with uniform heat generation

Answers with Explanation (Objective)

Heat Transfer from Extended Surfaces (Fins)

Objective Questions (IES, IAS, GATE)

1. From a metallic wall at 100°C, a metallic rod protrudes to the ambient air. The temperatures at the tip will be minimum when the rod is made of **[IES-1992]**
(a) aluminium (b) stool (d) copper (d) silver
1. Ans. (b)

Heat flow through "Rectangular fin"

Heat dissipation from an infinitely long fin

2. The temperature distribution in a stainless fin (thermal conductivity 0.17 W/cm°C) of constant cross -sectional area of 2 cm^2 and length of 1-cm, exposed to ambient of 40°C (with a surface heat transfer coefficient of 0.0025 W/cm^{20}C) is given by $(T - T_\infty) = 3x^2 - 5x + 6$, where T is in °C and x is in cm. If the base temperature is 100°C, then the heat dissipated by the fin surface will be **[IES-1994]**
(a) 6.8 W (b) 3.4 W (c) 1.7 W (d) 0.17 W.
2. Ans. (b) Heat dissipated by fin surface

$$= \sqrt{\frac{hP}{kA}}\frac{t_1 - t_2}{x/kA} = \sqrt{\frac{0.0025\times 2}{0.17\times 1}}\times\frac{100-40}{1/0.17\times 2} = 3.4W$$

Heat dissipation from a fin insulated at the tip

3. The insulated tip temperature of a rectangular longitudinal fin having an excess (over ambient) root temperature of θ_o is **[IES-2002]**

(a) $\theta_o \tanh(ml)$ (b) $\frac{\theta_o}{\sinh(ml)}$ (c) $\frac{\theta_o \tanh(ml)}{(ml)}$ (d) $\frac{\theta_o}{\cosh(ml)}$

3. Ans. (d)

4. The efficiency of a pin fin with insulated tip is **[IES-2001]**

(a) $\frac{\tanh mL}{(hA/kP)^{0.5}}$ (b) $\frac{\tanh mL}{mL}$ (c) $\frac{mL}{\tanh mL}$ (d) $\frac{(hA/kP)^{0.5}}{\tanh mL}$

4. Ans. (b)

Heat dissipation from a fin losing heat at the tip

5. A fin of length 'l' protrudes from a surface held at temperature t_o greater than the ambient temperature t_a. The heat dissipation from the free end' of the fin is assumed to be negligible. The temperature gradient at the fin tip $\left(\frac{dt}{dx}\right)_{x=l}$ is **[IES-1999]**

(a) zero (b) $\frac{t_1 - t_a}{t_o - t_a}$ (c) $h(t_o - t_1)$ (d) $\frac{t_o - t_l}{l}$

5. Ans. (a)

Efficiency and effectiveness of fin

6. Usually fins are provided to increase the rate of heat transfer. But fins also act as insulation. Which one of the following non-dimensional numbers decides this factor?
(a) Eckert number (b) Biot number (c) Fourier number (d) Peclet number **[IES 2007]**
6. Ans. (b)

7. Provision of fins on a given heat transfer surface will be more it there are **[IES-1992]**
(a) fewer number of thick fins (b) fewer number of thin fins
(c) large number of thin fins (d) large number of thick fins
7. Ans. (c)

8. In order to achieve maximum heat dissipation, the fin should be designed in such a way that: **[IES-2005]**
(a) It should have maximum lateral surface at the root side of the fin
(b) It should have maximum lateral surface towards the tip side of the fin
(c) It should have maximum lateral surface near the centre of the fin
(d) It should have minimum lateral surface near the centre of the fin
8. Ans. (a)

9. A finned surface consists of root or base area of 1 m^2 and fin surface area of 2 m^2. The average heat transfer coefficient for finned surface is 20 W/m^2K. Effectiveness of fins provided is 0.75. If finned surface with root or base temperature of 50°C is transferring heat to a fluid at 30°C, then rate of heat transfer is **[IES-2003]**
(a) 400 W (b) 800 W (c) 1000 W (d) 1200 W
9. Ans. (b)

10. Consider the following statements pertaining to large heat transfer rate using fins:
1. Fins should be used on the side where heat transfer coefficient is small
2. Long and thick fins should be used **[IES-2002]**
3. Short and thin fins should be used
4. Thermal conductivity of fin material should be large

Which of the above statements are correct?
(a) 1, 2 and 3 (b) 1, 2 and 4 (c) 2, 3 and 4 (d) 1, 3 and 4
10. Ans. (d)

11. Assertion (A): In a liquid-to-gas heat exchanger fins are provided in the gas side.
Reason (R): The gas offers less thermal resistance than liquid **[IES-2002]**
11. Ans. (c)

12. Assertion (A): Nusselt number is always greater than unity. **[IES-2001]**
Reason (R): Nusselt number is the ratio of two thermal resistances, one the thermal resistance which would be offered by the fluid, if it was stationary and the other, the thermal resistance associated with convective heat transfer coefficient at the surface.
12. Ans. (b)

13. Addition of fin to the surface increases the heat transfer if $\sqrt{hA/KP}$ is **[IES-1996]**
(a) equal to one (b) greater than one

(c) less than one (d) greater than one but less than two.

13. Ans. (c) Addition of fin to the surface increases the heat transfer if $\sqrt{hA/KP}$ <<1.

14. Consider the following statements pertaining to heat transfer through fins:
1. Fins are equally effective irrespective of whether they are on the hot side or cold side of the fluid. **[IES-1996]**
2. The temperature along the fin is variable and hence the rate of heat transfer varies along the elements of the fin.
3. The fins may be made of materials that have a higher thermal conductivity than the material of the wall.
4. Fins must be arranged at right angles to the direction of flow of the working fluid.
Of these statements
(a) 1 and 2 are correct (b) 2 and 4 are correct (c) 1 and 3 are correct (d) 2 and 3 are correct.

14. Ans. (b) Statement 1 is wrong because fins are effective on hot side of fluid for dissipating heat. Statement 2 is correct. Statement 3 is wrong because it is good enough to have same material for wall and fin. Statement 4 is correct. This right alternative is (b), i.e. statements 2 and 4 are correct.

15. In spite of large heat transfer coefficients in boiling liquids, fins are used advantageously when the entire surface is exposed to **[IES-1994]**
(a) nucleate boiling (b) film boiling
(c) transition boiling (d) all modes of boiling.

15. Ans. (d) Fins are used advantageously in all modes of boiling.

Estimation of error in temperature measurement in a thermometer well

16. When the fluid velocity is doubled, the thermal time constant of a thermometer used for measuring the fluid temperature reduces by a factor of 2. **[GATE-1994]**

16. Ans. False

Time constant by, $\Gamma = \frac{V.P.C}{Ah}$,

where
V = Volume (m^3),
ρ = density (kg/m^3),
C = specific heat kJ/kgK,
A = Area (m^2),
h = surface film conductance W/M^2K.

When the velocity is doubled, h increases, thus τ, the time constant decreases. But it is not halved as the increase of 'h' is not two times due to the doubling of velocity.

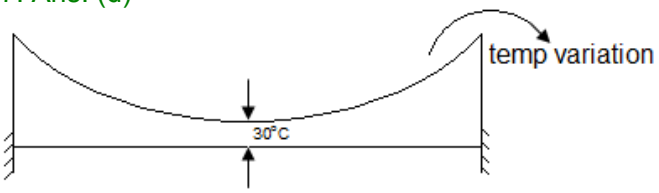
(Since $= \frac{k}{\delta}$; therefore reduction of boundary layer thickness 'δ' is not linearly connected with variation in velocity).

Heat transfer from a bar connected to the two heat sources at different, temperatures

17. A metallic rod of uniform diameter and length L connects two heat sources each at 500^0C. The atmospheric temperature is 30^0C. The temperature gradient $\frac{dT}{dL}$ at the centre of the bar will be

(a) $\frac{500}{L/2}$ (b) $-\frac{500}{L/2}$ (c) $-\frac{470}{L/2}$ (d) zero **[IAS-2001]**

17. Ans. (d)



Answers with Explanation (Objective)

4. One Dimensional Unsteady Conduction

Objective Questions (IES, IAS, GATE)

Heat Conduction in Solids having Infinite Thermal Conductivity (Negligible internal Resistance-Lumped Parameter Analysis)

1. The value of Biot number is very small (less than 0.01) when **[GATE-2002]**
(a) the convective resistance of the fluid is negligible
(b) the conductive resistance of the fluid is negligible
(c) the conductive resistance of the solid is negligible
(d) none of these
1. Ans. (c)

2. Lumped heat transfer analysis of a solid object suddenly exposed to a fluid medium at a different temperature is valid when **[GATE-2001]**
(a) Biot number < 0.1 (b) Biot number> 0.1
(c) Fourier number < 0.1 (d) Fourier number> 0.1

2. Ans. (a) Biot Number $(B_i)=\frac{hL_c}{k}$ is the ratio of internal (conduction) resistance to surface (convection) resistance. When the value of B_i is small, it means the system has a small internal (conduction) resistance, i.e. relatively small temperature gradient or existence of practical uniform temperature within the system. The convective resistance then predominates and transient phenomenon is controlled by the convective heat exchange.

3. The ratio $\frac{\text{surface convection resistance}}{\text{internal conduction resistance}}$ is known as **[IES-1992]**
(a) Grashoff number (b) Biot number (c) Stanton number (b) Prandtl number
3. Ans. (b)

4. Which one of the following statements is correct? **[IES-2004]**
The curve for unsteady state cooling or heating of bodies
(a) parabolic curve asymptotic to time axis
(b) exponential curve asymptotic to time axis
(c) exponential curve asymptotic both to time and temperature axis
(d) hyperbolic curve asymptotic both to time and temperature axis
4. Ans. (b) $\frac{Q}{Q_o}=e^{-B_i\times F_o}$

5. A small copper ball of 5 mm diameter at 500 K is dropped into an oil bath whose temperature is 300 K. The thermal conductivity of copper is 400 W/mK, its density 9000 kg/m^3 and its specific heat 385 Jlkg.K.1f the heat transfer coefficient is 250 W/m^2K and lumped analysis is assumed to be valid, the rate of fall of the temperature of the ball at the beginning of cooling will be, in K/s,
(a) 8.7 (b) 13.9 (c) 17.3 (d) 27.7 **[GATE-2005]**

5. Ans. (a) Charactaristic length $(L_c) = \frac{V}{A_s} = \frac{\frac{4}{3}\pi r^3}{4\pi r^2} = \frac{r}{3} = \frac{0.005/2}{3} = 8.3333 \times 10^{-4}\,m$

Thermal diffusivity, $\alpha = \frac{k}{\rho c_p} = \frac{400}{9000 \times 385} = 1.1544 \times 10^{-4}$

Fourier Number $(F_o) = \frac{\alpha\tau}{L_c^2} = 166\tau$

Biot Number $(B_i) = \frac{hL_c}{k} = \frac{250 \times 8.3333 \times 10^{-4}}{400} = 5.208 \times 10^{-4}$

Then

$\frac{\theta}{\theta_i} = \frac{T - T_a}{T_i - T_a} = e^{-B_i \times F_o}$ or $\frac{T - 300}{500 - 300} = e^{-166\tau \times 5.208 \times 10^{-4}}$

or $\ln(T - 300) - \ln 200 = -0.08646\tau$

or $\frac{1}{(T - 300)}\frac{dT}{d\tau} = -0.08646$ or $\left(\frac{dT}{d\tau}\right)_{T \approx 500K} = -0.08646 \times (500 - 300) = -17.3\,K/s$

6. A spherical thermocouple junction of diameter 0.706 mm is to be used for the measurement of temperature of a gas stream. The convective heat transfer co-efficient on the bead surface is 400 W/m^{2}K. Thermophysical properties of thermocouple material are k = 20 W/mK, C =400 J/kg K and ρ = 8500 kg/m^3. If the thermocouple initially at 30°C is placed in a hot stream of 300°C, then time taken by the bead to reach 298°C, is

(a) 2.35 s (b) 4.9 s (c) 14.7 s (d) 29.4 s **[GATE-2004]**

6. Ans. (b) Characteristic length $(L_c) = \frac{V}{A} = \frac{\frac{4}{3}\pi r^3}{4\pi r^2} = \frac{r}{3} = 0.11767 \times 10^{-3}\,m$

Biot Number $(B_i) = \frac{hL_c}{k} = \frac{400 \times (0.11767 \times 10^{-3})}{20} = 2.3533 \times 10^{-3}$

As $B_i < 0.1$ the lumped heat capacity approach can be used

$\alpha = \frac{k}{\rho c_p} = \frac{20}{8500 \times 400} = 5.882 \times 10^{-6}\,m^2/s$

Fourier Number $(F_o) = \frac{\alpha\tau}{L_c^2} = 425\tau$

$\frac{\theta}{\theta_i} = e^{-F_o.B_i}$ or $F_o.B_i = \ln\left(\frac{\theta}{\theta_i}\right)$ or $425\tau \times 2.3533 \times 10^{-3} = \ln\left(\frac{300 - 30}{300 - 298}\right)$ or $\tau = 4.9\,s$

7. Assertion (A): In lumped heat capacity systems the temperature gradient within the system is negligible **[IES-2004]**

Reason (R): In analysis of lumped capacity systems the thermal conductivity of the system material is considered very high irrespective of the size of the system

7. Ans. (c) If Biot number (Bi)= $\frac{hL_c}{k} = \frac{h}{k}.\left(\frac{V}{A_s}\right) < 0.1$ then use lumped heat capacity approach. It depends on size.

8. A solid copper ball of mass 500 grams, when quenched in a water bath at 30°C, cools from 530°C to 430°C in 10 seconds. What will be the temperature of the ball after the next 10 seconds? **[IES-1997]**

(a) 300°C (b) 320°C
(c) 350°C (d) Not determinable for want of sufficient data

8. Ans. (c) In first 10 seconds, temperature is fallen by 100°C. In next 10 seconds fall will be less than 100°C. :. 350°C appears correct solution.

9. The temperature distribution with in thermal boundary layer over a heated isothermal flat plate is given by $\frac{T - T_w}{T_\infty - T_w} = \frac{3}{2}\left(\frac{y}{\delta_t}\right) - \frac{1}{2}\left(\frac{y}{\delta_t}\right)^3$, where T_w and T_∞ are the temperature of plate and free stream respectively, and y is the normal distance measured from the plate. The local Nusselt number based on the thermal boundary layer thickness δ_t is given by **[GATE-2007]**

(a) 1.33 (b) 1.50 (c) 2.0 (d) 4.64

9. Ans. (d)

Time Constant and Response of -Temperature Measuring Instruments

10. A thermocouple in a thermo-well measures the temperature of hot gas flowing through the pipe. For the most accurate measurement of temperature, the thermo-well should be made of: **[IES-1997]**

(a) steel (b) brass (c) copper (d) aluminium

10. Ans. (c) Copper being best conductor compared to other materials is preferred for accurate measurement

11. Assertion (A): During the temperature measurement of hot gas in a duct that has relatively cool walls, the temperature indicated by the thermometer will be lower than the true hot gas temperature.
Reason(R): The sensing tip of thermometer receives energy from the hot gas and loses heat to the duct walls. **[IAS-2000]**

11. Ans. (a)

Transient Heat Conduction in Solids with Finite conduction and Convective Resistances ($0 < H_i < 100$),

Transient. Heat Conduction in Semi-infinite Solids (*h* or H_i 4.5. 30-5 00),

12. Heisler charts are used to determine transient heat flow rate and temperature distribution when: **[IES-2005]**

(a) Solids possess infinitely large thermal conductivity
(b) Internal conduction resistance is small and convective resistance is large
(c) Internal conduction resistance is large and the convective resistance is small
(d) Both conduction and convention resistance are almost of equal significance

12. Ans. (d)

Systems with Periodic Variation of Surface Temperature

Transient Conduction with Given Temperature Distribution,

Answers with Explanation (Objective)

Free & Forced convection

Objective Questions (IES, IAS, GATE)

1. The properties of mercury at 300 K are: density = 13529 kg/m^3, specific heat at constant pressure = 0.1393 kJ/kg-K, dynamic viscosity = 0.1523 x 10-2 N.s/m^2 and thermal conductivity = 8.540 W/m-K. The Prandtl number of the mercury at 300 K is
(a) 0.0248 (b) 2.48 (c) 24.8 (d) 248 **[GATE-2002]**

1. Ans. (a) $P_r = \frac{\mu C_p}{k} = \frac{0.1523 \times 10^{-2} \times (0.1393 \times 1000)}{8.540} = 0.0248$

2. For calculation of heat transfer by natural convection from a horizontal cylinder, what is the characteristic length in Grashof Number?
(a) Diameter of the cylinder
(b) Length of the cylinder
(c) Circumference of the base of the cylinder
(d) Half the circumference of the base of the cylinder. **[IES 2007]**
2. Ans. (c)

3. Assertion (A): A slab of finite thickness heated on one side and held horizontal will lose more heat per unit time to the cooler air if the hot surface faces upwards when compared with the case where the hot surface faces downwards. **[IES-1996]**
Reason (R): When the hot surface faces upwards, convection takes place easily whereas when the hot surface faces downwards, heat transfer is mainly by conduction through air.
3. Ans. (a) Both A and R are true, and R is correct explanation for A

4. For the fully developed laminar now and heat transfer in a uniformly heated long circular tube, if the now velocity is doubled and the tube diameter is halved, the heat transfer coefficient will be
(a) double of the original value (b) half of the original value **[IES-2000]**
(c) same as before (d) four times of the original value
4. Ans. (b)

5. Assertion (A): According to Reynolds analogy for Prandtl number equal to unity. Stanton number is equal to one half of the friction factor. **[IES-2001]**
Reason (R): If thermal diffusivity is equal to kinematic viscosity, the velocity and the temperature distribution in the flow will be the same.
5. Ans. (c)

6. The Nusselt number is related to Reynolds number in laminar and turbulent flows respectively as **[IES-2000]**
(a) $Re^{-1/2}$ and $Re^{0.8}$ (b) $Re^{1/2}$ and $Re^{0.8}$ (c) $Re^{-1/2}$ and $Re^{-0.8}$ (d) $Re^{1/2}$ and $Re^{-0.8}$
6. Ans. (b)

7. In respect of free convection over a vertical flat plate the Nusselt number varies with Grashof number 'Gr' as **[IES-2000]**
(a) Gr and $Gr^{1/4}$ for laminar and turbulent flows respectively
(b) $Gr^{1/2}$ and $Gr^{1/3}$ for laminar and turbulent flows respectively
(c) $Gr^{1/4}$ and $Gr^{1/3}$ for laminar and turbulent flows respectively

(d) $Gr^{1/3}$ and $Gr^{1/4}$ for laminar and turbulent flows respectively

7. Ans. (a)

8. Heat is lost from a 100 mm diameter steam pipe placed horizontally in ambient at 30°C. If the Nusselt number is 25 and thermal conductivity of air is 0.03 W/mK, then the heat transfer co-efficient will be **[IES-1999]**

(a) 7.5 W/m^{2}K (b) 16.2 W/m^{2}K (c) 25.2 W/m^2 K (d) 30 W/m^{2}K

8. Ans. (a) $\frac{hl}{k} = N_u$, or $h = \frac{25 \times 0.03}{0.1} = 7.5\ \text{W/m}^2\text{K}$

9. Match List I with II and select the correct answer using the code given below the Lists:

List I (Non-dimensional Number)	List II (Application)
A. Grashof number	1. Mass transfer
B. Stanton number	2. Unsteady state heat conduction
C. Sherwood number	3. Free convection
D. Fourier number	4. Forced convection

Code: **[IES 2007]**

	A	B	C	D		A	B	C	D
(a)	4	3	1	2	(b)	3	4	1	2
(c)	4	3	2	1	(d)	3	4	2	1

9. Ans. (b)

10. Match List I (Type of heat transfer) with List II (Governing dimensionless parameter) and select the correct answer: **[IES-2002]**

List I	List II
A. Forced convection	1. Reynolds, Grashof and Prandtl number
B. Natural convection	2. Reynolds and Prandtl number
C. Combined free and forced convection	3. Fourier modulus and Biot number
D. Unsteady conduction with convection at surface	4. Prandtl number and Grashof number

	A	B	C	D		A	B	C	D
(a)	2	1	4	3	(b)	3	4	1	2
(c)	2	4	1	3	(d)	3	1	4	2

10. Ans. (c)

11. For steady, uniform flow through pipes with constant heat flux supplied to the wall, what is the value of Nusselt number? **[IES 2007]**

(a) 48/11 (b) 11/48 (c) 24/11 (d) 11/24

11. Ans. (a)

12. Which one of the following non-dimensional numbers is used for transition from laminar to turbulent flow in free convection?

(a) Reynolds number (b) Grashof number

(c) Peclet number (d) Rayleigh number **[IES 2007]**

12. Ans. (d)

13. Nusselt number for fully developed turbulent flow in a pipe is given by $N_u = CR_e^a P_r^b$. The values of a and b are **[IES-2001]**

(a) a = 0.5 and b = 0.33 for heating and cooling both
(b) a = 0.5 and b = 0.4 for heating and b = 0.3 for cooling
(c) a = 0.8 and b = 0.4 for heating and b = 0.3 for cooling
(d) a = 0.8 and b = 0.3 for heating and b = 0.4 for cooling
13. Ans. (c)

14. For natural convective now over a vertical flat plate as shown in the given figure, the governing differential equation for momentum is **[IES-2001]**

$$\left(u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}\right)=g\beta(T-T_\infty)+\gamma\frac{\partial^2 u}{\partial y^2}$$

If equation is non-dimensionalized by $U=\frac{u}{U_\infty}$, $V=\frac{u}{U_\infty}$, $X=\frac{x}{L}$, $Y=\frac{y}{L}$ and $\theta=\frac{T-T_\infty}{T_s-T_\infty}$ then the term $g\beta(T-T_\infty)$, is equal to

(a) Grashof number (b) Prandtl number (c) Rayleigh number (d) $\frac{\text{Grashof number}}{(\text{Reynolds number})^2}$

14. Ans. (c)

15. Match List - I with List - II and select the correct answer using the code given below the Lists: **[IES-2006]**

List - I (Phenomenon)	List – II (Associated Dimensionless Parameter)
A. Transient conduction	1. Reynolds number
B. Forced convection	2. Grashoff number
C. Mass transfer	3. Biot number
D. Natural convection	4. Mach number
	5. Sherwood number

	A	B	C	D		A	B	C	D
(a)	3	2	5	1	(b)	5	1	4	2
(c)	3	1	5	2	(d)	5	2	4	1

15. ans. (c)

16.Which one of the following numbers represents the ratio of kinematic viscosity to the thermal diffusivity? **[IES-2005]**
(a) Grashoff number (b) Prandtl number (c) Mach number (d) Nusselt number
16. Ans. (b)

17. Nusselt number for a pipe flow heat transfer coefficient is given by the equation $Nu_D = 4.36$. Which one of the following combinations of conditions do exactly apply for use of this equation? **[IES-2004]**
(a) Laminar flow and constant wall temperature
(b) Turbulent flow and constant wall heat flux
(c) Turbulent flow and constant wall temperature
(d) Laminar flow and constant wall heat flux
17. Ans. (*)

18. A fluid of thermal conductivity 1.0 W/m-K flows in fully developed flow with Reynolds number of 1500 through a pipe of diameter 10 cm. The heat transfer coefficient for uniform heat flux and uniform wall temperature boundary conditions are, respectively

(a) 36.57 and $43.64 \frac{W}{m^2K}$ (b) 43.64 and $36.57 \frac{W}{m^2K}$ **[IES-2002]**

(c) $43.64 \frac{W}{m^2K}$ for both the cases (d) $36.57 \frac{W}{m^2K}$ for both the cases

18. Ans. (b)

19. Match List I (Process) with List II/ (Predominant Parameter Associated with the Flow) and select the correct answer: **[IES-2004]**

List I	List II
A. Transient conduction	1. Sherwood Number
B. Mass transfer	2. Mach Number
C. Forced convection	3. Biot Number
D. Free convection	4. Grashof Number
	5. Reynolds number

	A	B	C	D		A	B	C	D
(a)	1	3	5	4	(b)	3	1	2	5
(c)	3	1	5	4	(d)	1	3	2	5

19. Ans. (c)

20. Which one of the following statements is correct? **[IES-2004]**
The non-dimensional parameter known as Stanton number (St) is used in
(a) forced convection heat transfer in flow over flat plate
(b) condensation heat transfer with laminar film layer
(c) natural convection heat transfer over flat plate
(d) unsteady heat transfer from bodies in which internal temperature gradients cannot be neglected

20. Ans. (a)

21. A 320 cm high vertical pipe at 150°C wall temperature is in a room with still air at 10°C. This pipe supplies heat at the rate of 8 kW into the room air by natural convection. Assuming laminar flow, the height of the pipe needed to supply 1 kW only is **[IES-2002]**
(a) 10 cm (b) 20 cm (c) 40 cm (d) 80 cm

21. Ans. (b)

22. The average Nusselt number in laminar natural convection from a vertical wall at 180°C with still air at 20°C is found to be 48. If the wall temperature becomes 30°C, all other parameters remaining same, the average Nusselt number will be **[IES-2002]**
(a) 8 (b) 16 (c) 24 (d) 32

22. Ans. (c)

23. Match List-I (Process) with List-II (Predominant Parameter Associated with the Process) and select the correct answer using the codes given below the Lists: **[IES-2003]**

List-I (Process)	List-II (Predominant Parameter Associated with the Process)
A. Mass transfer	1. Reynolds Number
B. Forced convection	2. Sherwood Number
C. Free convection	3. Mach Number
D. Transient conduction	4. Biot Number
	5. Grashoff Number

Codes:	A	B	C	D		A	B	C	D

(a) 5 1 2 3 (b) 2 1 5 4
(c) 4 2 1 3 (d) 2 3 5 4

23. Ans. (b)

24. The velocity and temperature distribution in a pipe flow are given by u(r) and T(r). If u_m is the mean velocity at any section of the pipe, the bulk mean temperature at that section is **[IES-2003]**

(a) $\int_0^{r_0} u(r)T(r)r^2dr$ (b) $\int_0^{r_0} \frac{u(r)}{3r}\frac{T(r)}{2r}dr$ (c) $\int_0^{r_0} \frac{u(r)T(r)}{2\pi r_0^3}dr$ (d) $\frac{2}{u_m r_0^2}\int_0^{r_0} u(r)T(r)rdr$

24. Ans. (d)

25. For fully-developed turbulent flow in a pipe with heating, the Nusselt number N_u, varies with Reynolds number R_e and Prandtl number P_r as **[IES-2003]**

(a) $R_e^{0.5}P_r^{\frac{1}{3}}$ (b) $R_e^{0.8}P_r^{0.2}$ (c) $R_e^{0.8}P_r^{0.4}$ (d) $R_e^{0.8}P_r^{0.3}$

25. Ans. (c)

26. For laminar flow over a flat plate, the local heat transfer coefficient 'h_x' varies as $x^{-1/2}$, where x is the distance from the leading edge (x = 0) of the plate. The ratio of the average coefficient' h_a' between the leading edge and some location 'A' at x = x on the plate to the local heat transfer coefficient 'h_x' at A is **[IES-1999]**

(a) 1 (b) 2 (c) 4 (d) 8

26. Ans. (b)

$$\text{Here at } x=0, h_o=h, \text{ and } \quad \text{at } x=x,\ h_x=\frac{h}{\sqrt{x}}$$

$$\text{Average coefficient}=\frac{1}{x}\int_0^x \frac{h}{\sqrt{x}}dx=\frac{2h}{\sqrt{x}} \qquad \text{Therefore ratio}=\frac{\frac{2h}{\sqrt{x}}}{\frac{h}{\sqrt{x}}}=2$$

27. When there is a flow of fluid over a flat plate of length 'L', the average heat transfer number; (other symbols have the usual meaning) **[IES-1997]**

$(a)\int_0^L h_x dx$ $(b)\frac{d}{dx}(h_x)$ $(c)\frac{1}{L}\int_0^L h_x dx$ $(d)\frac{k}{L}\int_0^L Nu_x dx$

27. Ans. (c)

28. In the case of turbulent flow through a horizontal isothermal cylinder of diameter' D', free convection heat transfer coefficient from the cylinder will **[IES-1997]**

(a) be independent of diameter (b) vary as $D^{3/4}$ (c) vary as $D^{1/4}$ (d) vary as $D^{1/2}$

28. Ans. (a) Free convection heat transfer coefficient from the cylinder is independent of its diameter.

29. Match List t with List II and select the correct answer using the codes given below the lists:

[IES-1993]

List I (Dimensionless quantity)	List II (Application)
A. Stanton number	1. Natural convection for ideal gases

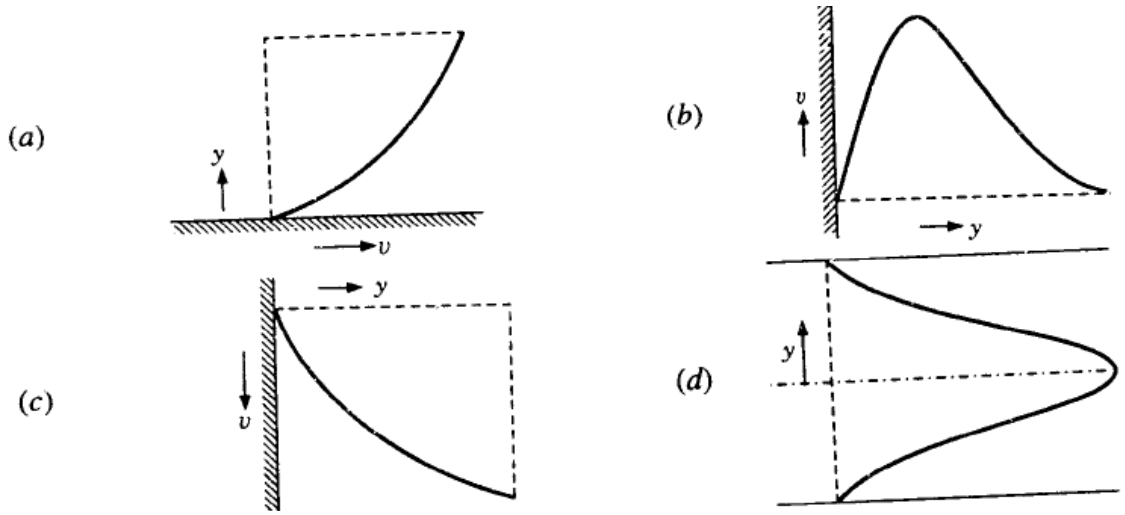
B. Grashof number 2. Mass transfer
C. Peclet number 3. Forced convection
D. Schmidt number 4. Forced convection for small Prandtl number

Codes:	A	B	C	D		A	B	C	D
(a)	2	4	3	1	(b)	3	1	4	2
(c)	3	4	1	2	(d)	2	1	3	4

29. Ans. (b) The correct matching for various dimensionless quantities is provided by code (b)

30. Assertion (A): All analyses of heat transfer in turbulent flow must eventually rely on experimental data. **[IES-2000]**
Reason (R): The eddy properties vary across the boundary layer and no adequate theory is available to predict their behaviour.
30. Ans. (a)

31.



Match the velocity profiles labelled A, B, C and D with the following situations:**[IES-1998]**

1. Natural convection 2. Condensation 3. Forced convection
4. Bulk viscosity $\neq$ wall viscosity 5. Flow in pipe entrance
Select the correct answer using the codes given below:

Code:	A	B	C	D		A	B	C	D
(a)	3	2	1	5	(b)	1	4	2	3
(c)	3	2	1	4	(d)	2	1	5	3

31. Ans. (a) It provides right matching

32. Consider the following statements: **[IES-1997]**
If a surface is pock-marked with a number of cavities, then as compared to a smooth surface
1. radiation will increase. 2. nucleate boiling will increase.
3. conduction will increase. 4. convection will increase.
Of these statements
(1) 1, 2 and 3 are correct (b) 1, 2 and 4 are correct
(c) 1, 3 and 4 are correct (d) 2, 3 and 4 are correct

32. Ans. (a) Convection heat transfer is independent of condition of surface

33. Given that
N_u = Nusselt number, R_e = Reynolds number, P_r = Prandtl number **[IES-1997]**
S_h = Sherwood number, S_c = Schmidt number and G_r = Grashoff number
the functional relationship for free convective mass transfer is given as :
$(a)\, N_u = f(G_r, P_r)$ $(b)\, S_h = f(S_c, G_r)$ $(c) N_u = f(R_r, P_r)$ $(d)\, S_h = f(R_e, S_c)$
33. Ans. (a)

34. A cube at high temperature is immersed in a constant temperature bath. It loses heat from its top, bottom and side surfaces with heat transfer coefficient of h_1, h_3 and h_3 respectively. The average heat transfer coefficient for the cube is **[IES-1996]**

$(a)\, h_1 + h_3 + h_3$ $(b)\, (h_1 h_3 h_3)^{1/3}$ $(c)\, \frac{1}{h_1} + \frac{1}{h_2} + \frac{1}{h_3}$ (d) none of the above

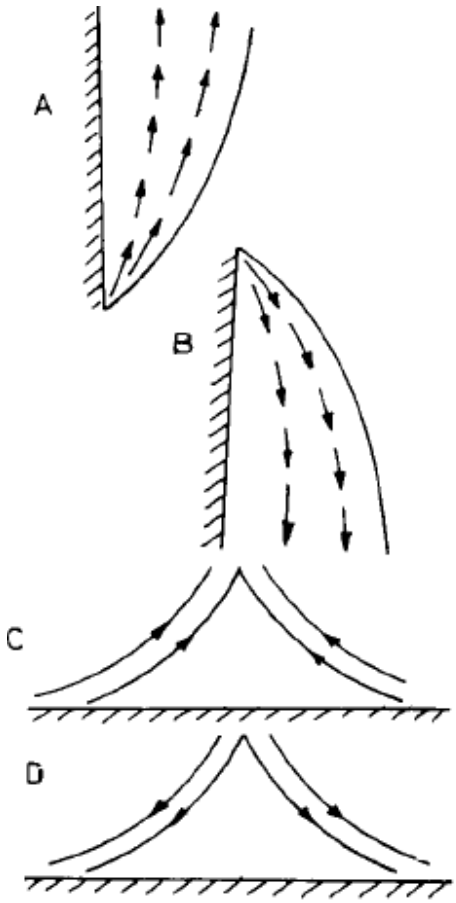
34. Ans. (a) Losing of heat from top, bottom and side surfaces of cubes is equivalent to considering that resistances, to heat flow are in parallel. For parallel resistance
$\frac{1}{R_{av}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$ or $h_{av} = h_1 + h_3 + h_3$

35. Assertion (A): When heat is transferred from a cylinder in cross flow to an air stream, the local heat transfer coefficient at the forward stagnation point is large. **[IES-1995]**
Reason (R): Due to separation of the boundary layer eddies continuously sweep the surface close to the forward stagnation point.
35. Ans. (a) A and R are correct. R is right explanation for A.

36. In free convection heat transfer transition from laminar to turbulent flow is governed by the critical value of the **[IES-1992]**
(a) Reynolds number (b) Grashoff's number
(c) Reynolds number, Grashoff number (d) Prandtl number, Grashoff number
36. Ans. (d)

97. Most of the relations for free convection are expressed as
Laminar flow : $10^4 < Gr\,Pr < 10^9$, $Nu = 0.13\,(Gr.Pr)^{0.25}$
Turbulent flow : $10^9 < Gr.Pr\ 10^{12}$, $Nu = 0.53\,(Gr.Pr)^{0.33}$

37. Match List I with List II and select the correct answer using the codes given below the lists:
List I (Flow Pattern) List II (Situation) **[IES-1995]**



1. Heated horizontal plate
2. Cooled horizontal plate
3. Heated vertical plate
4. Cooled vertical plate

Codes:	A	B	C	D		A	B	C	D
(a)	4	3	2	1	(b)	3	4	1	2
(c)	3	4	2	1	(d)	4	3	1	2

37. Ans. (b)

38. Consider a hydrodynamically fully developed flow of cold air through a heated pipe of radius r_o. The velocity and temperature distributions in the radial direction are given by u(r) and T(r) respectively. If u_m, is the mean velocity at any section of the pipe, then the bulk-mean temperature at that section is given by **[IES-1994]**

(a) $\int_0^{r_o} u(r)T(r)r^2dr$ (b) $\int_0^{r_o} \frac{u(r)}{3r}\frac{T(r)}{2r}dr$ (c) $\frac{4\int_0^{r_o} u(r)T(r)dr}{2\pi r_o^3}$ (d) $\frac{2}{u_m r_o^2}\int_0^{r_o} u(r)T(r)rdr$

38. Ans. (d)

$$\text{Bulk-mean temperature} = \frac{\text{total thermal energy crossing a sectionpipe in unit time}}{\text{heat capacity offluid crossing same section in unit time}}$$

$$= \frac{\int_0^{r_o} u(r)T(r)rdr}{u_m\int_0^{r_o} rdr} = \frac{2}{u_m r_o^2}\int_0^{r_o} u(r)T(r)rdr$$

39. The ratio of energy transferred by convection to that by conduction is called
(a) Stanton number (b) Nusselt number (c) Biot number (d) Preclet number
[IES-1992]

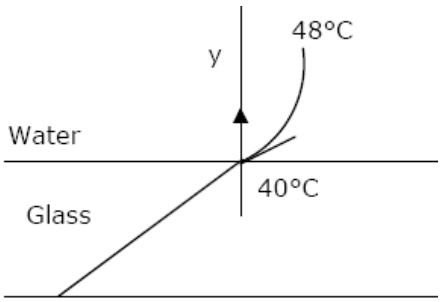
39. Ans. (b)

40. Free convection flow depends on all of the following EXCEPT **[IES-1992]**
(a) density (b) coefficient of viscosity (c) gravitational force (d) velocity
40. Ans. (d)

41. The average heat transfer coefficient on a thin hot vertical plate suspended in still air can be determined from observations of the change in plate temperature with time as it cools. Assume the plate temperature to be uniform at any instant of time and radiation heat exchange with the surroundings negligible. The ambient temperature is 25°C, the plate has a total surface area of 0.1 m^2 and a mass of 4 kg. The specific heat of the plate material is 2.5 kJ/kgK. The convective heat transfer coefficient in W/m^2K, at the instant when the plate temperature is 225°C and the change in plate temperature with time dT/dt = - 0.02 K/s, is: **[GATE-2007]**
(a) 200 (b) 20 (c) 15 (d) 10
41. Ans. (d)

Data for Q. 42 - 43 are given below. Solve the problems and choose correct answers.

Heat is being transferred by convection from water at 48°C to a glass plate whose surface that is exposed to the water is at 40°C. The thermal conductivity of water is 0.6 W/mK and the thermal conductivity of glass is 1.2 W/mK. The spatial Water gradient of temperature in the water at the water-glass interface is dT/dy =1 x 10^4 K/m.



[GATE-2003]

42. The value of the temperature gradient in the glass at the water-glass interface in K/m is **[GATE-2003]**
(a) - 2 x 10^4 (b) 0.0 (c) 0.5 x 10^4 (d) 2 x 10^4
42. Ans. (c) $K_w = 0.6\,W/mK, \quad K_G = 1.2\,W/mK$
The spatial gradient of temperature in water at the water-glass interface

$$= \left(\frac{dT}{dy}\right)_w = 1\times10^4\,K/m$$

At Water glass interface,

$$Q = K_w\left(\frac{dT}{dy}\right)_w = K_G\left(\frac{dT}{dy}\right)_G \quad \text{or} \quad \left(\frac{dT}{dy}\right)_G = \frac{K_w}{K_G}\left(\frac{dT}{dy}\right)_w = \frac{0.6}{1.2}\times10^4 = 0.5\times10^4\,K/m$$

43. The heat transfer coefficient h in W/m^2K is **[GATE-2003]**
(a) 0.0 (b) 4.8 (c) 6 (d) 750
43. Ans. (d)
Heat transfer per unit area q = h (T_f – T_i)

$$\text{or } h = \frac{q}{T_f - T_i} = \frac{K_w\left(\frac{dT}{dy}\right)_w}{T_f - T_i} = \frac{0.6\times10^4}{(48-40)} = 750\,W/m^2K$$

44. If velocity of water inside a smooth tube is doubled, the n turbulent flow heat transfer coefficient between the water and the tube will **[GATE-1999]**

(a) remain unchanged (b) increase to double its value

(c) increase but will not reach double its value (d) increase to more than double its value

44. Ans. (c) $\bar{h} = 0.023\frac{k}{D}(Re)^{0.8}(Pr)^{\frac{1}{3}} = 0.023\frac{k}{D}\left(\frac{\rho VD}{\mu}\right)^{0.8}\left(\frac{\mu c_p}{k}\right)^{\frac{1}{3}}$

So $\bar{h} \propto v^{0.8}$ and $Q \propto \bar{h}$ Therefore $\frac{Q_2}{Q_1} = \left(\frac{v_2}{v_1}\right)^{0.8} = 2^{0.8} = 1.74$

Answers with Explanation (Objective)

5. Boiling and Condensation

Objective Questions (IES, IAS, GATE)

Boiling Heat Transfer

1. Consider the following statements:
The effect of fouling in a water-cooled steam condenser is that it **[IES-1997]**
1. reduces the heat transfer coefficient of water.
2. reduces the overall heat transfer coefficient.
3. reduces the area available for heat transfer.
4. increases the pressure drop of water
Of these statements
(a) 1. 2 and 4 are correct (b) 2, 3 and 4 are correct
(c) 2 and 4 are correct (d) 1 and 3 are correct
1. Ans. (b) Heat transfer coefficient of water remains unaffected with fouling

2. Consider the following phenomena: **[IES-1997]**
1. Boiling 2. Free convection in air 3. Forced convection 4. Conduction in air.
Their correct sequence in increasing order of heat transfer coefficient is:
(a) 4, 2, 3, 1 (b) 4, 1, 3, 2 (c) 4, 3, 2, 1 (d) 3, 4, 1, 2
2. Ans. (a) Air being insulator, heat transfer by conduction is least. Next is free convection, followed by forced convection. Boiling has maximum heat transfer

3. Consider the following statements regarding condensation heat transfer:
1. For a single tube, horizontal position is preferred over vertical position for better heat transfer.
2. Heat transfer coefficient decreases if the vapour stream moves at high velocity.
3. Condensation of steam on an oily surface is dropwise. **[IES-1996]**
4. Condensation of pure benzene vapour is always dropwise.
Of these statements
(a) 1 and 2 are correct (b) 2 and 4 are correct (c) 1 and 3 are correct (d) 3 and 4 are correct.
3. Ans. (a) Statements 1 and 2 are correct and statements 3 and 4 are incorrect

4. When all the conditions are identical, in the case of flow through pipes with heat transfer, the velocity profiles will be identical for: **[IES-1997]**
(a) liquid heating and liquid cooling (b) gas heating and gas cooling
(c) liquid heating and gas cooling (d) heating and cooling of any fluid
4. Ans. (a) The velocity profile for flow through pipes with heat transfer is identical for liquid heating and liquid cooling.

5. Drop wise condensation usually occurs on **[IES-1992]**
(a) glazed surface (b) smooth surface (c) oily surface (d) coated surface
5. Ans. (c)

Boiling regimes

Bubble shape and size consideration

Bubble growth and collapse

Critical diameter of bubble

Factors affecting nucleate boiling

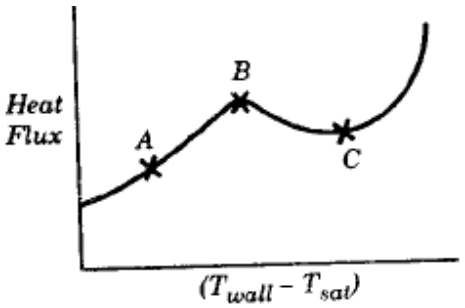
6. Consider the following statements regarding nucleate boiling; **[IES-1995]**
1. The temperature of the surface is greater than the saturation temperature of the liquid.
2. Bubbles are created by the expansion of entrapped gas or vapour at small cavities in the surface.
3. The temperature is greater than that of film boiling.
4. The heat transfer from the surface to the liquid is greater than that in film boiling.
Of these correct statements are:
(a) 1, 2 and 4 (b) 1 and 3 (c) 1, 2 and 3 (d) 2, 3 and 4
6. Ans. (a)

7. The burnout heat flux in the nucleate boiling regime is a function of which of the following properties? **[IES-1993]**
1. Heat of evaporation 2. Temperature difference
3. Density of vapour 4. Density of liquid 5. Vapour-liquid surface tension.
Select the correct answer using the codes given below:
Codes: (a) 1, 2, 4 and 5 (b) 1, 2, 3 and 5 (c) 1, 3, 4 and 5
(d) 2, 3 and 4
7. (a) Density of vapour affects the film boiling and does not have much role during nucleate boiling. Factors 1, 2, 4 and 5 come into picture for burnout heat flux in the nucleate boiling regime.

Boiling correlations

Nucleate pool boiling

8. The given figure shows a pool-boiling curve. Consider the following statements in this regard:
1. Onset of nucleation causes a marked change in slope.
2. At the point B, heat transfer coefficient is the maximum.
3. In an electrically heated wire submerged in the liquid, film heating is difficult to achieve.
4. Beyond the point C, radiation becomes significant **[IES-1997]**



Of these statements
(a) 1, 2 and 4 are correct (b) 1, 3 and 4 are correct
(c) 2, 3 and 4 are correct (d) 1, 2 and 3 are correct
8. Ans. (a)

9. Assertion (A): If the heat fluxes in pool boiling over a horizontal surface is increased above the critical heat flux, the temperature difference between the surface and liquid decreases sharply. **[IES-2003]**
Reason (R): With increasing heat flux beyond the value corresponding to the critical heat flux, a stage is reached when the rate of formation of bubbles is so high that they start to coalesce and blanket the surface with a vapour film.
9. Ans. (b)

Critical heat flux for nucleate pool boiling

Film pool boiling

Condensation Heat Transfer

10. Saturated steam is allowed to condense over a vertical flat surface and the condensate film flows down the surface. The local heat transfer coefficient for condensation
(a) remains constant at all locations of the surface **[IES-1999]**
(b) decreases with increasing distance from the top of the surface
(c) increases with increasing thickness of condensate film
(d) increases with decreasing temperature differential between the surface and vapour.
10. Ans. (a)

11. Consider the following statements: **[IES-1998]**
1. If a condensing liquid does not wet a surface drop wise, then condensation will take place on it.
2. Drop wise condensation gives a higher heat transfer rate than film-wise condensation.
3. Reynolds number of condensing liquid is based on its mass flow rate.
4. Suitable coating or vapour additive is used to promote film-wise condensation.
Of these statements
(a) 1 and 2 are correct (b) 2, 3 and 4 are correct
(c) 4 alone is correct (d) 1, 2 and 3 are correct
11. Ans. (c)

12. Assertion (A): Even though dropwise condensation is more efficient, surface condensers are designed on the assumption of film wise condensation as a matter of practice. **[IES-1995]**
Reason (R): Dropwise condensation can be maintained with the use of promoters like oleic acid.
12. Ans. (b) A and R are true. R is not correct reason for A.

13. Assertion (A): The rate of condensation over a rusty surface is less than that over a polished surface. **[IES-1993]**
Reason (R): The polished surface promotes drop wise condensation which does not wet the surface.
13. Ans. (a) Both A and R are true and R provides satisfactory explanation for A.

Laminar film condensation on a vertical plate

Turbulent film condensation

Film condensation on horizontal tubes

Film condensation inside horizontal tubes

Influence of the presence of non condensable gases

Answers with Explanation (Objective)

6. Heat Exchangers

Objective Questions (IES, IAS, GATE)

Types of Heat Exchangers, 529

1. Air can be best heated by steam in a heat exchanger of **[IES-2006]**
(a) Plate type (b) Double pipe type with fins on steam side
(c) Double pipe type with fins on air side (d) Shell and tube type
1. Ans. (c)

2. Which one of the following heat exchangers gives parallel straight line pattern of temperature distribution for both cold and hot fluid?
(a) Parallel-flow with unequal heat capacities (b) Counter-flow with equal heat capacities
(c) Parallel-flow with equal heat capacities
(d) Counter-flow with unequal heat capacities **[IES-2001]**
2. Ans. (b)

3. Match List I (Heat Exchanger Process) with List II (Temperature Area Diagram) and select the correct answer: **[IES-2004]**

List I

A. Counter flow sensible heating

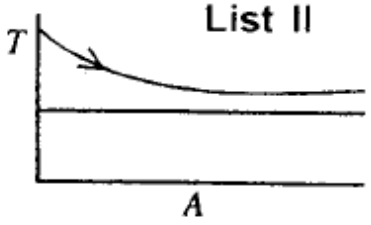
B. Parallel flow sensible heating

C. Evaporating

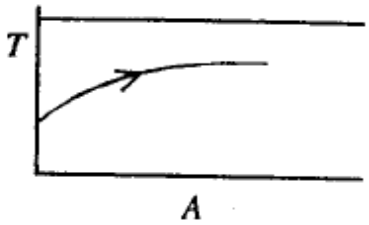
D. Condensing

List II

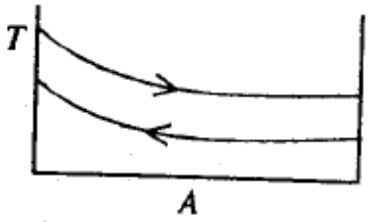
1.



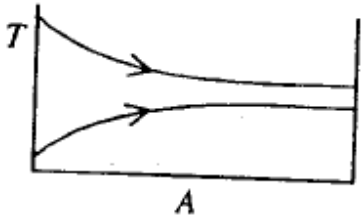
2.

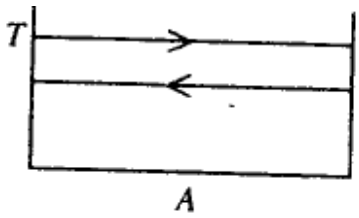


3.



4.



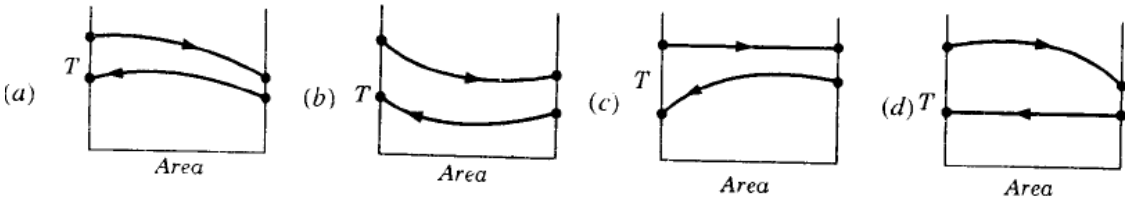
5. 

	A	B	C	D		A	B	C	D
(a)	3	4	1	2	(b)	3	2	5	1
(c)	4	3	2	5	(d)	4	2	1	5

3. Ans. (a)

4. Consider the following statements:
The flow configuration in a heat exchanger, whether counterflow or otherwise, will **NOT** matter if
1. a liquid is evaporating 2. a vapour is condensing
3. mass flow rate of one of the fluids is far greater **[IES-1997]**
Of these statements
(a) 1 and 2 are correct (b) 1 and 3 are correct (c) 2 and 3 are correct (d) 1, 2 and 3 are correct
4. Ans. (a) If liquid is evaporating or a vapour is condensing then whether heat exchanger is counterflow or otherwise is immaterial. Same matters for liquid/gas flows.

5. Which one of the following diagrams correctly shows the temperature distribution for a gas-to-gas counterflow heat exchanger? **[IES-1997]**



5. Ans. (a) Fig. (a) is for gas to gas counterflow.

6. Match List I with List II and select the correct answer using the codes given below the lists:

List I	List II
A. Regenerative heat exchanger	1. Water cooling tower
B. Direct contact heat exchanger	2. Lungstrom air heater
C. Conduction through a cylindrical wall	3. Hyperbolic curve
D. Conduction through a spherical wall	4. Logarithmic curve

[IES-1995]

Codes:	A	B	C	D		A	B	C	D
(a)	1	4	2	3	(b)	3	1	4	2
(c)	2	1	3	4	(d)	2	1	4	3

6. Ans. (b)

7. Match List I with List II and select the correct answer
List I List II **[IES-1994]**

A. Number of transfer units	1. Recuperative type heat exchanger
B. Periodic flow heat exchanger	2. Regenerator type heat exchanger
C. Chemical additive	3. A measure of the heat exchanger size

D. Deposition on heat exchanger surface 4. Prolongs drop-wise condensation
5. Fouling factor

Codes:	A	B	C	D		A	B	C	D
(a)	3	2	5	4	(b)	2	1	4	5
(c)	3	2	4	5	(d)	3	1	5	4

7. Ans. (c)

8. Consider the following statements: **[IES-1994]**
In a shell and tube heat exchanger, baffles are provided on the shell side to
1. prevent the stagnation of shell side fluid 2. improve heat transfer
3. provide support for tubes
Select the correct answer using the codes given below:
(a) 1, 2, 3 and 4 (b) 1, 2 and 3 (c) 1 and 2 (d) 2 and 3
8. Ans. (d) Baffles help in improving heat transfer and also provide support for tubes

9. In a counter flow heat exchanger, for the hot fluid the heat capacity = 2 kJ/kg K, mass flow rate = 5 kg/s, inlet temperature = 150°C, outlet temperature = 100°C. For the cold fluid, heat capacity = 4 kJ/kg K, mass flow rate = 10 kg/s, inlet temperature = 20°C. Neglecting heat transfer to the surroundings, the outlet temperature of the cold fluid in °C is **[GATE-2003]**
(a) 7.5 (b) 32.5 (c) 45.5 (d) 70.0
9. Ans. (b)
Let temperature t°C
Heat loss by hot water = heat gain by cold water

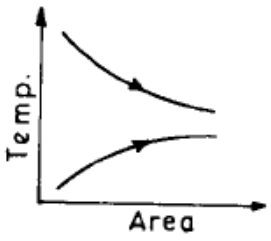
$$\dot{m}_h c_{ph}\left(t_{h1}-t_{h2}\right)=\dot{m}_c c_{pc}\left(t_{c2}-t_{c1}\right)$$

or $5\times 2\times(150-100)=10\times 4\times(t-20)$

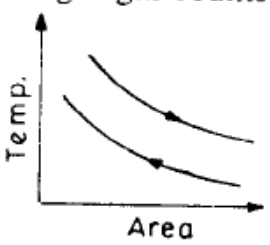
or $t=32.5^{\circ}C$

10. Which one of the following diagrams represents correctly the gas-gas counter flow heat exchange? **[IES-1994]**

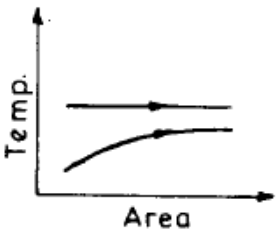
(a)



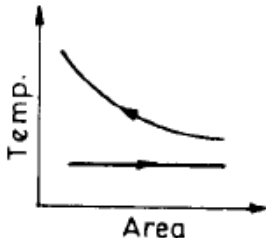
(b)



(c)



(d)



10. Ans. (b) Figure (b) represents correctly the gas-gas counter flow exchanger since temperature of hot stream continuously falls and that of cold stream continuously increases.

Logarithmic Mean Temperature Difference (LMTD), 535

11. Assertion (A): It is not possible to determine LMTD in a counter flow heat exchanger with equal heat capacity rates of hot and cold fluids, **[IES-2002]**
Reason (R): Because the temperature difference is invariant along the length of the heat exchanger.
11. Ans. (a)

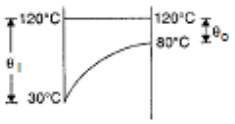
12. Assertion (A): A counter flow heat exchanger is thermodynamically more efficient than the parallel flow type. **[IES-2003]**
Reason (R): A counter flow heat exchanger has a lower LMTD for the same temperature conditions.
12. Ans. (c)

13. In a counter-flow heat exchanger, the hot fluid is cooled from 110° C to 80° C by a cold fluid which gets heated from 30° C to 60° C. LMTD for the heat exchanger is
(a) 20° C (b) 30° C (c) 50° C (d) 80° C **[IES-2001]**
13. Ans. (b)

14. In a condenser, water enters at 30°C and flows at the rate 1500 kg/hr. The condensing steam is at a temperature of 120°C and cooling water leaves the condenser at 80°C. Specific heat of water is 4.187 kJ/kg K. If the overall heat transfer coefficient is 2000 W/m^{2}K, then heat transfer area is **[GATE-2004]**
(a) 0.707 m^2 (b) 7.07 m^2 (c) 70.7 m^2 (d) 141.4 m^2
14. Ans. (a)

$\theta_i = 120 - 30 = 90$

$\theta_o = 120 - 80 = 40$



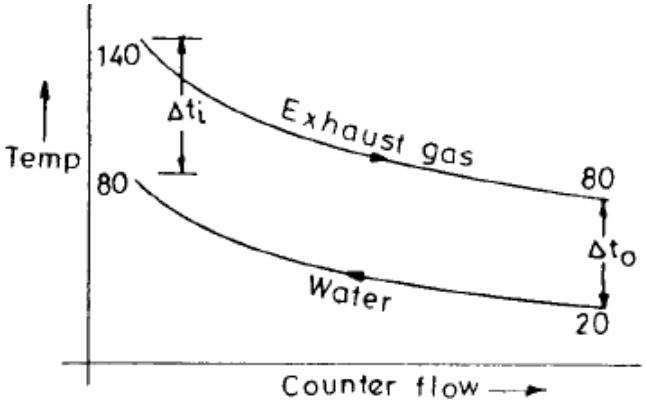
$$\text{LMTD} = \frac{\theta_i - \theta_o}{\ln\left(\frac{\theta_i}{\theta_o}\right)} = \frac{90 - 40}{\ln\left(\frac{90}{40}\right)} = 61.66^\circ\text{C}$$

$$\dot{Q} = \dot{m}c_p\left(t_{c2} - t_{c1}\right) = UA\left(\text{LMTD}\right)$$

$$\text{or } A = \frac{\left(\frac{1500}{3600}\right) \times 4.187 \times 10^3 \times (80 - 30)}{2000 \times 61.66} = 0.707\,\text{m}^2$$

15. Assertion (A): The LMTD for counterflow is larger than that of parallel flow for a given temperature of inlet and outlet. **[IES-1998]**
Reason (R): The definition of LMTD is the same for both counterflow and parallel flow.
15. Ans. (b) Both statements are correct but R is not exactly correct explanation for A

16. A counterflow heat exchanger is used to heat water from 20°C to 80°C by using hot exhaust gas entering at 140° C and leaving at 80°C. The log mean temperature difference for the heat exchanger is
(a) 80° C
(b) 60°C
(c) 110°C
(d) not determinable as zero/zero is involved



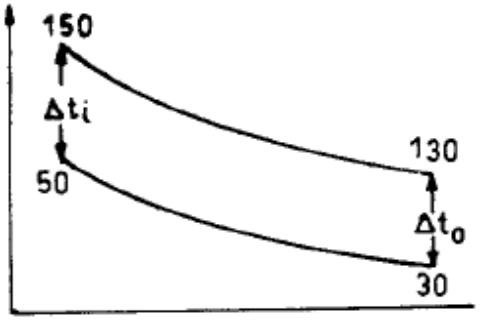
[IES-1996]

16. Ans. (b) LMTD = $\frac{\Delta t_o - \Delta t_i}{\log_e\left(\Delta t_o / \Delta t_i\right)}$ will be applicable when $\Delta t_i \neq \Delta t_o$

and if $\Delta t_i \neq \Delta t_o$ *then* $LMTD = \Delta t_i = \Delta t_o$

17. For evaporators and condensers, for the given conditions, the logarithmic mean temperature difference (LMTD) for parallel flow is **[IES-1993]**
(a) equal to that for counter flow (b) greater than that for counter flow
(c) smaller than that for counter flow (d) very much smaller than that for counter flow
17. (c) The LMID for parallel flow is smaller than for counter flow.

18. In a counter flow heat exchanger, cold fluid enters at 30°C and leaves at 50°C, whereas the enters at 150°C and leaves at l30°C. The mean temperature difference for this case is
(a) indeterminate (b) 20°C (c) 80°C (d) 100°C **[IES-1994]**
18. Ans. (d) Mean temperature difference = $\Delta t_i = \Delta t_o = 100^\circ C$



19. A designer chooses the values of fluid flow ranges and specific heats in such a manner that the heat capacities of the two fluids are equal. A hot fluid enters the counter flow heat exchanger at 100°C and leaves at 60°C. The cold fluid enters the heat exchanger at 40bC. The mean temperature difference between the two fluids is temperature difference between the two fluids is:
(a) (100 +60 + 40)/3°C (b) 60°C (c) 40°C (d) 20°C **[IES-1993]**
19. Ans. (d) Mean temperature difference
= temperature of hot fluid at exit - temperature of cold fluid at entry
= 60° - 40° = 20°C

20. The logarithmic mean temperature difference (LMTD) of a counterflow heat exchanger is 20^0C. The cold f1uid enters at 20^0C and the hot fluid enters at 100°C. Mass fl0w rate of the cold fluid is twice that of the hot fluid. Specific heat at constant pressure of the hot fluid is twice that of the cold fluid. The exit temperature of the cold fluid
(A) is 40^0C (B) is 60^0C (C) is 80^0C (D) cannot be determined **[GATE-2008]**
20. Ans (C) as $m_h c_h = m_c c_c$ Therefore Exit Temp. = 100 – LMTD = 100 – 20 =80 ^{o}C

21. In a counter flow heat exchanger, hot fluid enters at 60°C and cold fluid leaves at 30°C. Mass flow rate of the hot fluid is 1 kg/s and that of the cold fluid is 2 kg/s. Specific heat of the hot fluid is 10 kJ/kgK and that of the cold fluid is 5 kJ/kgK. The Log Mean Temperature Difference (LMTD) for the heat exchanger in °C is: **[GATE-2007]**
(a) 15 (b) 30 (c) 35 (d) 45
21. Ans. (b)

22. Hot oil is cooled from 80 to 50°C in an oil cooler which uses air as the coolant. The air temperature rises from 30 to 40°C. The designer uses a LMTD value of 26°C. The type of heat exchanger is **[GATE-2005]**
(a) parallel flow (b) double pipe (c) counter flow (d) cross flow)
22. Ans. (d)

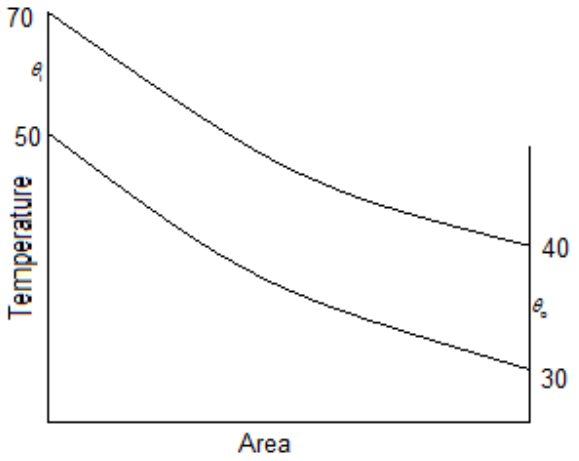
23. For the same inlet and outlet temperatures of hot and cold fluids, the Log Mean Temperature Difference (LMTD) is **[GATE-2002]**
(a) greater for parallel flow heat exchanger than for counter flow heat exchanger.
(b) greater for counter flow heat exchanger than for parallel flow heat exchanger.
(c) same for both parallel and counter flow heat exchangers.
(d) dependent on the properties of the fluids.
23. Ans. (b)

24. Air enters a counter flow heat exchanger at 70°C and leaves at 40°C. Water enters at 30°C and leaves at 50°C. The LMTD in degree C is **[GATE-2000]**
(a) 5.65 (b) 4.43 (c) 19.52 (d) 20.17
24. Ans. (b)

$\theta_i = 70 - 50 = 20$

$\theta_o = 40 - 30 = 10$

$$\text{LMTD} = \frac{\theta_i - \theta_o}{\ln\left(\frac{\theta_i}{\theta_o}\right)} = \frac{20 - 10}{\ln\left(\frac{20}{10}\right)} = 14.43^\circ$$



Overall Heat Transfer Coefficient, 539

25. Given the following data, **[IES-1993]**
inside heat transfer coefficient = 25 W/m^2°K
outside heat transfer coefficient = 25 W/m^2°K
thermal conductivity of bricks (15 cm thick) = 0.15 W/mK,
the overall heat transfer coefficient (in W/m^{2}K) will be closer to the
(a) inverse of heat transfer coefficient (b) heat transfer coefficient
(c) thermal conductivity of bricks
(d) heat transfer coefficient based on the thermal conductivity of the bricks alone

25. Ans. (d) Overall coefficient of heat transfer U W/m^{2}K is expressed as

$\frac{1}{U}=\frac{1}{h_i}+\frac{\Delta x}{k}+\frac{1}{h_o}=\frac{1}{25}+\frac{0.15}{0.15}+\frac{1}{25}=\frac{27}{25}$ so U = $\frac{25}{27}$ which is closer to the heat transfer coefficient based on the bricks alone.

Heat Exchanger Effectiveness and Number of Transfer Units (NTU), 582

26. When t_{c1} and t_{c2} are the temperatures of cold fluid at entry and exit respectively and t_{h1} and t_{h2} are the temperatures of hot fluid at entry and exit point, and cold fluid has lower heat capacity rate as compared to hot fluid, then effectiveness of the heat exchanger is given by **[IES-1992]**

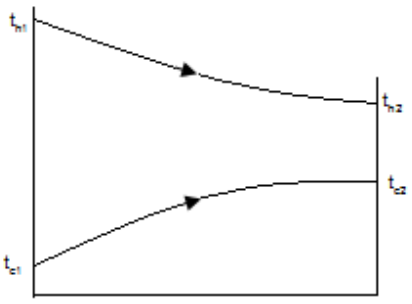
$(a)\frac{t_{c1}-t_{c2}}{t_{h1}-t_{c1}}$ $(b)\frac{t_{h2}-t_{h1}}{t_{c2}-t_{h1}}$ $(c)\frac{t_{h1}-t_{h2}}{t_{h2}-t_{c1}}$ $(d)\frac{t_{c2}-t_{c2}}{t_{h1}-t_{c1}}$

26. Ans. (d)

27. In a certain heat exchanger, both the fluids have identical mass flow rate-specific heat product. Tire hot fluid enters at 76°C and leaves at 47°C and tire cold fluid entering at 26°C leaves at 55°C. The effectiveness of tire heat exchanger is **[GATE-1997]**

27. Ans. (b)

$$\text{Effectiveness}(\varepsilon)=\frac{Q}{Q_{max}}=\frac{t_{c2}-t_{c1}}{t_{h1}-t_{c1}}$$
$$=\frac{55-26}{76-26}=0.58$$



28. In a parallel flow gas turbine recuperator, the maximum effectiveness is **[IES-1992]**
(a) 100% (b) 75% (c) 50% (b) between 25% and 45%

28. Ans. (c)

54. For parallel flow configuration, effectiveness $\epsilon = \frac{1-\exp(-2NTU)}{2}$

$\therefore$ Limiting value of ϵ is therefore $\frac{1}{2}$ or 50%.

29. In a heat exchanger with one fluid evaporating or condensing the surface area required is least in **[IES-1992]**
(a) parallel flow (b) counter flow (c) cross flow (d) same in all above
29. Ans. (d)

30. The equation of effectiveness **[IES-2006]**
E = $1-e^{-NTU}$ for a heat exchanger is valid in the case of
(a) Boiler and condenser for parallel now
(b) Boiler and condenser for counter flow
(c) Boiler and condenser for both parallel flow and counterflow
(d) Gas turbine for both parallel now and counterflow
30. Ans. (c)

$$\in=\frac{1-e^{-NTU\left(1+\frac{C_{\min}}{C_{\max}}\right)}}{1+\frac{C_{\min}}{C_{\max}}}=1-e^{-NTU}\ For\ Parallerl\ \ flow[As\,boiler\ and\ condenser\ \frac{C_{\min}}{C_{\max}}\to 0]$$

$$=\frac{1-e^{-NTU\left(1+\frac{C_{\min}}{C_{\max}}\right)}}{1+\frac{C_{\min}}{C_{\max}}e^{-NTU\left(1+\frac{C_{\min}}{C_{\max}}\right)}}=1-e^{-NTU}\ \ For\,Counter\ \ flow$$

31. After expansion from a gas turbine, the hot exhaust gases are used to heat the compressed air from a compressor with the help of a cross flow compact heat exchanger of 0.8 effectiveness. What is the number of transfer units of the heat exchanger?
(a) 2 (b) 4 (c) 8 (d) 16 **[IES-2005]**
31. Ans. (b) Effectiveness, $\varepsilon=\frac{\text{NTU}}{1+\text{NTU}}=0.8$

32. The equation of effectiveness $\varepsilon=1-e^{-NTU}$ of a heat exchanger is valid (NTU is number or transfer units) in the case of
(a) boiler and condenser for parallel flow
(b) boiler and condenser for counterflow
(c) boiler and condenser for both parallel flow and counterflow **[IES-2000]**
(d) gas turbine for both parallel flow and counterflow
32. Ans. (d)

33. In a counterflow heat exchanger, the product of specific heat and mass flow rate is same for the hot and cold fluids. If NTU is equal to 0.5, then the effectiveness of the heat exchanger is
(a) 1.0 (b) 0.5 (c) 0.33 (d) 0.2 **[IES-2001]**
33. Ans. (d)

34. Match List I with List II and select the correct answer using the codes given below the Lists (Notations have their usual meanings): **[IES-2000]**

List I	List II
A. Fin	1. $\frac{UA}{C_{\min}}$

B. Heat exchanger 2. $\frac{x}{2\sqrt{\alpha\tau}}$

C. Transient conduction 3. $\sqrt{\frac{hp}{kA}}$

D. Heisler chart 4. hl/k

Code:	A	B	C	D		A	B	C	D
(a)	3	1	2	4	(b)	2	1	3	4
(c)	3	4	2	1	(d)	2	4	3	1

34. Ans. (a)

35. A cross-flow type air-heater has an area of 50 m^2. The overall heat transfer coefficient is 100 W/m^2K and heat capacity of both hot and cold stream is 1000 W/K. The value of NTU is

(a) 1000 (b) 500 (c) 5 (d) 0.2 **[IES-1999]**

35. Ans. (c)

$$\text{NTU} = \frac{\text{AU}}{\text{C}_{\min}},\ \text{A} = \text{area} = 50\text{m}^2,\ \text{U} = \text{overall heat transfer coefficient} = 100\ \text{W/m}^2\text{K}$$

$$\text{C}_{\min} = \text{heat capacity} = 1000\ \text{W/K}\ \therefore \text{NTU} = \frac{50\times100}{1000} = 5$$

36. A heat exchanger with heat transfer surface area A and overall heat transfer coefficient U handles two fluids of heat capacities C_1, and C_2, such that $C_1 > C_2$. The NTU of the heat exchanger is given by **[IES-1996]**

36. Ans. (a) NTU (number of transfer units) used in analysis of heat exchanger is specified as AU/C_{min}

37. A counterflow shell - and - tube exchanger is used to heat water with hot exhaust gases. The water (C_p= 4180 J/kg°C) flows at a rate of 2 kg/s while the exhaust gas (1030 J/kg°C) flows at the rate of 5.25 kg/s. If the heat transfer surface area is 32.5 m^2 and the overall heat transfer coefficient is 200 $W/m^{2\circ}C$, what is the NTU for the heat exchanger?

(a) 1.2 (b) 2.4 (c) 4.5 (d) 8.6 **[IES-1995]**

37. Ans. (a)

38. A heat exchanger with heat transfer surface area A and overall heat transfer co-efficient U handles two fluids of heat capacities C_{max} and C_{min}. The parameter NTU (number of transfer units) used in the analysis of heat exchanger is specified as

(a) $\frac{AC_{\min}}{U}$ (b) $\frac{U}{AC_{\min}}$ (c) $UAC_{\min}$ (d) $\frac{UA}{C_{\min}}$ **[IES-1993]**

38. Ans. (d)

39. ε-NTU method is particularly useful in thermal design of heat exchangers when

(a) the outlet temperature of the fluid streams is not known as a priori

(b) outlet temperature of the fluid streams is known as a priori **[IES-1993]**

(c) the outlet temperature of the hot fluid streams is known but that of the cold fluid streams is not known as a priori

(d) inlet temperatures of the fluid streams are known as a priori

39. Ans. (a)

Answers with Explanation (Objective)

7. Radiation

Objective Questions (IES, IAS, GATE)

Introduction

1. Assertion (A): Heat transfer at high temperature is dominated by radiation rather than convection. **[IES-2002]**
Reason (R): Radiation depends on fourth power of temperature while convection depends on unit power relationship.
1. Ans. (a)

2. Assertion (A): In a furnace, radiation from the walls has the same wavelength as the incident radiation from the heat source. **[IES-1998]**
Reason (R): Surfaces at the same temperature radiate at the same wavelength.
2. Ans. (a)

3. Consider following parameters: **[IES-1995]**
1. Temperature of the surface 2. Emissivity of the surface
3. Temperature of the air in the room 4. Length and diameter of the pipe.
The parameter(s) responsible for loss of heat from a hot pipe surface in a room without fans would include
(a) 1 alone (b) 1 and 2 (c) 1, 2 and 3 (d) 1, 2, 3 and 4.
3. Ans. (d) All parameters are responsible for loss of heat from a hot pipe surface.

4. Which one of the following modes of heat transfer would take place predominantly, from boiler furnace to water wall? **[IES-1993]**
(a) Convection (b) Conduction (c) Radiation (d) Conduction and convection
4. Ans. (c) In boiler, the energy from flame is transmitted mainly by radiation to water wall and radiant super heater.

5. A solar engine uses a parabolic collector supplying the working fluid at 500°C. A second engine employs a flat plate collector, supplying the working fluid at 80°C. The ambient temperature is 27°C. The ratio maximum work obtainable in the two cases is
(a) 1 (b) 2 (c) 4 (d) 16 **[IES-1992]**
5. Ans. (c)

62. Max. efficiency of solar engine $= \frac{T_1 - T_2}{T_1}$

$$= \frac{(500+273)-(27+273)}{(50+273)} = \frac{473}{773}\left(=\frac{W_1}{Q_1}\right) \text{ say,}$$

where, W is the work output for Q_1 heat input.

Maximum efficiency of second engine $= \frac{(273+80)-(273+27)}{(273+80)} = \frac{53}{353}\left(=\frac{W_2}{Q_2} \text{ say}\right)$

where W_2 is the work output of second engine for Q_2 heat output.
Assuming same heat input for the two engines, we have

$$\therefore \quad \frac{W_1}{W_2} = \frac{473/733}{53/353} = 4$$

Absorptivity, Reflectivity and Transmissivity, 629

6. Consider the following statements: **[IES-1998]**

1. For metals, the value of absorptivity is high.
2. For non-conducting materials, reflectivity is low.
3. For polished surfaces, reflectivity is high.
4. For gases, reflectivity is very low.

Of these statements
(a) 2, 3 and 4 are correct (b) 3 and 4 are correct
(c) 1, 2 and 4 are correct (d) 1 and 2 are correct
6. Ans. (a) Statements 2, 3 and 4 are correct.

7. When α is absorbtivity, ρ is reflectivity and τ is transmisivity, then for diathermanous body, which of the following relation is valid? **[IES-1992]**
(a) α = 1, ρ = 0, τ = 0 (b) α = 0, ρ = 1, τ = 0 (c) α = 0, ρ = 0, τ = 1 (d) α + ρ = 1, τ = 0
7. Ans. (c)

8. In radiative heat transfer, a gray surface is one **[GATE-1997]**
(a) which appears gray to the eye (b) whose emissivity is independent of wavelength
(c) which has reflectivity equal to zero
(d) which appears equally bright from all directions.
8. Ans. (b)

9. On which of the following factors does sol-air temperature depend? **[IES-2003]**
1. Outdoor air temperature 2. Intensity of solar radiation 3. Absorptivity of wall
4. Convective heat transfer coefficient at outer surface of wall
5. Indoor design temperature
Choose the correct answer from the codes given below:
(a) 1, 2 and 5 (b) 1, 2 and 3 (c) 3 and 4 (d) 1, 2, 3 and 4
9. Ans. (d)

10. Match List I with List II and select the correct answer **[IES-1996]**

List I	List II
A. Window glass	1. Emissivity independent of wavelength
B. Gray surface	2. Emission and absorption limited to certain bands of wavelengths
C. Carbon dioxide	3. Rate at which radiation leaves a surface
D. Radiosity	4. Transparency to short wave radiation

Codes:	A	B	C	D		A	B	C	D
(a)	1	4	2	3	(b)	4	1	3	2
(c)	4	1	2	3	(d)	1	4	3	2

10. Ans. (a) The correct choice is (a), because for window glass, emissivity is independent of wavelength, gray surface has transparency to short wave length, for carbon dioxide the emission and absorption is limited to certain wave lengths, and radiosity is the rate at which radiation leaves a surface.

Black body, 630

11. Match List I with List II and select the correct answer: **[IES-2002]**

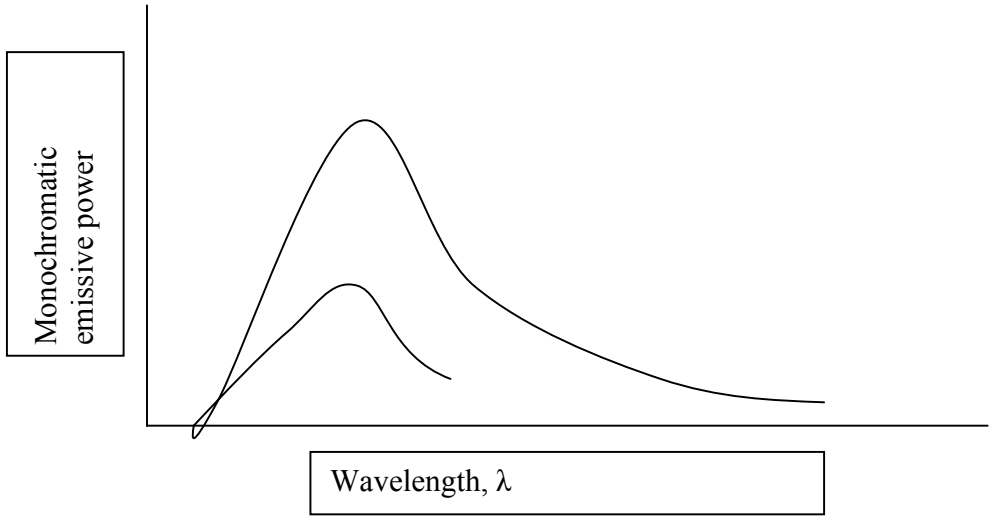
List I (Type of radiation)	List II (Characteristic)
A. Black body	1. Emissivity does not depend on wavelength

B. Grey body — 2. Mirror like reflection
C. Specular — 3. Zero reflectivity
D. Diffuse — 4. Intensity same in all directions

	A	B	C	D		A	B	C	D
(a)	2	1	3	4	(b)	3	4	2	1
(c)	2	4	3	1	(d)	3	1	2	4

11. Ans. (d)

12.



Consider the diagram given above. Which one of the following is correct?

(a) Curve A is for gray body, Curve B is for black body, and Curve C is for selective emitter.
(b) Curve A is for selective emitter, Curve B is for black body, and Curve C is for gray body
(c) Curve A is for selective emitter, Curve B is for grey body, and Curve C is for black body
(d) Curve A is for black body, Curve B is for gray body, and Curve C is for selective emitter. **[IES 2007]**

12. Ans. (d)

13. Assertion (A): The nose of aeroplane is painted black. **[IES-1996]**
Reason (R) Black body absorbs maximum heat which is generated by aerodynamic heating when the plane is flying.
13. Ans. (a) Both A and R are true, and R is correct explanation for A

The Stefan-Boltzmann Law

14. Two spheres A and B of same material have radii 1 m and 4 m and temperature 4000 K and 2000 K respectively

Which one of the following statements is correct? **[IES-2004]**
The energy radiated by sphere A is
(a) greater than that of sphere B (b) less than that of sphere B
(c) equal to that of sphere B (d) equal to double that of sphere B

14. Ans. (c) $E = \sigma A T^4 \;\therefore\; \frac{E_A}{E_B} = \frac{\frac{\pi r_A^2}{4} T_A^4}{\frac{\pi r_B^2}{4} \times T_B^4} = \frac{1^2 \times 4000^4}{4^2 \times (2000)^4} = 1$

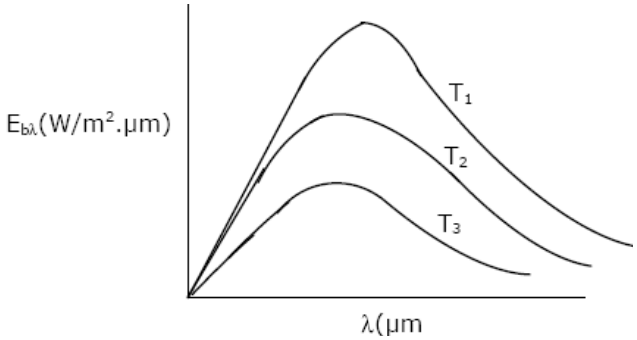
15. A body at 500 K cools by radiating heat to ambient atmosphere maintained at 300K. When the body has cooled to 400K, the cooling rate as a percentage of original cooling rate is about **[IES-2003]**
(a) 31.1 (b) 41.5 (c) 50.3 (d) 80.4
15. Ans. (a)

16. If the temperature of a solid surface changes from 27°C to 627°C, then its emissive power will increase in the ratio of **[IES-1999]**
(a) 3 (b) 9 (c) 27 (d) 81

16. Ans. (d) Emissive power is proportional to T^4 i.e. $\alpha \left(\frac{627+273}{27+273}\right)^4 = 3^4 = 81$

17. A spherical aluminium shell of inside diameter 2 m is evacuated and used as a radiation test chamber. If the inner surface is coated with carbon black and maintained at 600 K, the irradiation on a small test surface placed inside the chamber is (Stefan-Boltzmann constant $\sigma = 5.67 \times 10^{-8}$ W/m^{2}K^4) **[IES-1999]**
(a) 1000 W/m^2 (b) 3400 W/m^2 (c) 5680 W/m^2 (d) 7348 W/m^2
17. Ans. (d) Irradiation on a small test surface placed inside a hollow black spherical chamber = $\sigma T^4 = 5.67 \times 10^{-8} \times 6004 = 7348$ W/m^2

18. The following figure was generated from experimental data relating spectral black body emissive power to wavelength at three temperatures T_1, T_2 and T_3 ($T_1 > T_2 > T_3$).



The conclusion is that the measurements are
(a) correct because the maxima in $E_{b\lambda}$ show the correct trend
(b) correct because Planck's law is satisfied
(c) wrong because the Stefan Boltzmann law is not satisfied **[GATE-2005]**
(d) wrong because Wien's displacement law is not satisfied
18. Ans. (c)

19. A large spherical enclosure has a small opening. The rate of emission of radiative flux through this opening is 7.35 kW/m^2. The temperature at the inner surface of the sphere will be about (assume Stefan Boltzmann constants $\sigma = 5.67 \times 10^{-8}$ W/m^{2}K^4)
(a) 600 K (b) 330 K (c) 373 K (d) 1000 K **[IES-1998]**
19. Ans. (a)
Rate of emission of radiative flux $= \sigma T^4$ *or* $7.35 \times 10^3 = 5.67 \times 10^{-8} \times T^4$ *or* $T = 600\,K$

20. If the temperature of a solid state changes from 27°C to 627°C, then emissive power changes which rate **[IES-2006]**

(a) 6 : 1 (b) 9: 1 (c) 27 : 1 (d) 81: 1

20. Ans. (d) $\text{Emissive power (E)} = \varepsilon\sigma T^4$ *or* $\frac{E_1}{E_2} = \left(\frac{T_1}{T_2}\right)^4 = \left(\frac{300}{900}\right)^4 = \frac{1}{81}$

Kirchoff's Law, 631

21. What is the ratio of thermal conductivity to electrical conductivity equal to? **[IES-2006]**

(a) Prandtl number (b) Schmidt number (c) Lorenz number (d) Lewis number

21. Ans. (c)

22. Match List-I with List-II and select the correct answer using the codes given below the lists: **[IES-1999]**

List-I	List-II
A. Stefan-Boltzmann law	1. $q = hA(T_1 - T_2)$
B. Newton's law of cooling	2. $E = \alpha E_b$
C. Fourier's law	3. $q = \frac{kL}{A}(T_1 - T_2)$
D. Kirchoff'slaw	4. $q = \sigma A(T_1^4 - T_2^4)$
	5. $q = kA(T_1 - T_2)$

Code:	A	B	C	D		A	B	C	D
(a)	4	1	3	2	(b)	4	5	1	2
(c)	2	1	3	4	(d)	2	5	1	4

22. Ans. (c)

Planck's Law, 632

23. What is the basic equation of thermal radiation from which all other equations of radiation can be derived?

(a) Stefan-Boltzmann equation (b) Planck's equation **[IES 2007]**

(c) Wien's equation (d) Rayleigh-Jeans formula

23. Ans. (b)

24. The spectral emissive power E_λ for a diffusely emitting surface is **[IES-1998]**

$E_\lambda = 0$ for $\lambda < 3$ μm

$E_\lambda = 150$ W/m^{2}μm for $3 < \lambda < 12$ μm

$E_\lambda = 300$ W/m^{2}μm for $12 < \lambda < 25$ μm

$E_\lambda = 0$ for $\lambda > 25$ μm

The total emissive power of the surface over the entire spectrum is

(a) 1250 W/m^2 (b) 2500 W/m^2 (c) 4000 W/m^2 (d) 5250 W/m^2

24. Ans. (d) Total emissive power is defined as the total amount of radiation emitted by a body per unit time

$$i.e. \quad E = \int E_\lambda \lambda d\lambda = 0\times 3 + 150\times(12-3) + 300\times(25-12) + 0[\alpha]$$

$$= 150\times 9 + 300\times 13 = 1350 + 3900 = 5250\ \mathrm{W/m^2}$$

25. The wavelength of the radiation emitted by a body depends upon **[IES-1992]**
(a) the nature of its surface (b) the area of its surface
(c) the temperature of its surface (d) all the above factors.
25. Ans. (c)

Wien Displacement Law, 633

26. Match List I with List II and select the correct answer using the code given below the Lists: **[IES-2005]**

List I	List II
A Radiation heat transfer	1. Fourier number
B. Conduction heat transfer	2. Wien displacement law
C. Forced convection	3. Fourier law
D. Transient heat flow	4. Stanton number

	A	B	C	D		A	B	C	D
(a)	2	1	4	3	(b)	4	3	2	1
(c)	2	3	4	1	(d)	4	1	2	3

26. Ans. (c)

27. Sun's surface at 5800 K emits radiation at a wave-length of 0.5μ· A furnace at 300°C will emit through a small opening, radiation at a wavelength of nearly **[IES-1997]**
(a) 10 μ (b) 5 μ (c) 0.25 μ (d) 0.025 μ
27. Ans. (b) As per Wien's law, $\lambda_1 T_1 = \lambda_2 T_2$ *or* $5800\times 0.5 = \lambda_2 \times 573$

Intensity of Radiation and Lambert's Cosine Law, 634

28. Intensity of radiation at a surface in perpendicular direction is equal to:
(a) Product of emissivity of surface and 1/π **[IES-2005]**
(b) Product of emissivity of surface and π
(c) Product of emissive power of surface and 1/ π
(d) Product of emissive power of surface and π
28. Ans. (c)

29. Which one of the following statements is correct?
(a) in radian and its maximum value is π
(b) in degree and its maximum value is 180^0
(c) in steradian and its maximum value is 2 π
(d) in steradian and its maximum value is π **[IES 2007]**
29. Ans. (c)

30. What is the radiation intensity in a particular direction?

(a) Radiant energy per unit time per unit area of the radiating surface.
(b)Radiant energy per unit time per unit solid angle per unit area of the radiating surface
(c) Radiant energy per unit time per unit solid angle per unit projected area of the radiating surface in the given direction
(d) Radiant energy per unit time per unit projected area of the radiating surface in the given direction. **[IES 2007]**

30. Ans. (b) We know that, I = $\frac{E}{\pi}$

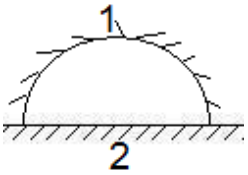
31. The earth receives at its surface radiation from the sun at the rate of 1400 W/m^2. The distance of centre of sun from the surface of earth is 15 x 10^{11} m and the radius of sun is 7.0 x 10^{8}m. What is approximately the surface temperature of the sun treating the sun as a black body? **[IES-2004]**
(a) 3650 K (b) 4500 K (c) 5800 (d) 6150 K
31. Ans. (c)

Radiation Exchange between Black Bodies Separates by a Non-absorbing Medium, 641

Shape Factor Algebra and Salient Features of the Shape Factor, 645

32. What is the value of the shape factor of two infinite parallel surface separated by a distance d? **[IES-2006]**
(a) 0 (b) ∞ (c) 1 (d) d
32. Ans. (c) All the emission from one plate will cross another plate. So Shape Factor in one.

33. What is the shape factor of a hemispherical body placed on a flat surface with respect to itself? **[IES-2005]**
(a) Zero (b) 0·25 (c) 0·5 (d) 1·0
33. Ans. (c)



$F_{2-1} + F_{2-2} = 1, \quad \because F_{2-2} = 0$ or $F_{2-1} = 1$

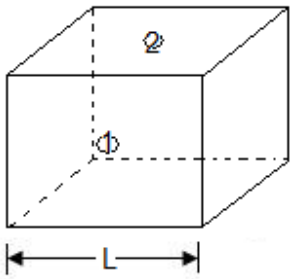
$A_1 F_{-2} = A F_{2-1}$

or $F_{1-2} = \frac{A_2}{A_1} \times F_{2-1} = \frac{\pi r^2 \times 1}{2\pi r^2} = \frac{1}{2}$

$F_{1-1} + F_{1-2} = 1$ or $F_{1-1} = \frac{1}{2} = 0.5$

34. A small sphere of outer area 0.6 m^2 is totally enclosed by a large cubical hall. The shape factor of hall with respect to sphere is 0.004. What is the measure of the internal side of the cubical hall? **[IES-2004]**
(a) 4 m (b) 5 m (c) 6 m (d) 10 m

34. Ans. (b) Shape factor F_{12} means part of radiation body 1 radiating and body 2 absorbing



$F_{11} + F_{12} = 1$

or $0 + F_{12} = 1$

then $A_1F_{12} = A_2F_{21}$ or A_2F_{21}

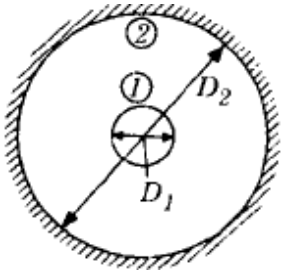
or $F_{21} = \frac{A_1}{A_2} \times F_{12} = \frac{0.6}{6L^2} \times 1 = 0.004$

or $L = \sqrt{\frac{0.6}{6 \times 0.004}} = 5m$

35. Consider two infinitely long blackbody concentric cylinders with a diameter ratio D_2/D_1 = 3. The shape factor for the outer cylinder with itself will be

(a) 0 (b) 1/3

(c) 2/3 (d) 1



[IES-1997]

35. Ans. (d) Shape factor for two infinitely long concentric cylinders is 1

36. What is the net radiant interchange per square meter for two very large plates at temperatures 800 K and 500 K respectively? (The emissivity of the hot and cold plates are 0.8 and 0.6 respectively. Stefan Boltzmann constant is 5.67 x 10^{-8} W/m^2 K^4). **[IES-1994]**

(a) 1.026 kW/m^2 (b) 10.26 kW/m^2 (c) 102.6 kW/m^2 (d) 1026 kW/m^2

36. Ans. (b) Heat transfer Q = $\sigma F_e F_A \left(T_1^4 - T_2^4\right) W/m^2$; σ = 5.67 x 10^{-8} W/m^2 K^4

F_e = effective emissivity coefficient = $\frac{1}{\frac{1}{\varepsilon_1} + \frac{1}{\varepsilon_2} - 1} = \frac{1}{\frac{1}{0.8} + \frac{1}{0.6} - 1} = \frac{12}{23}$

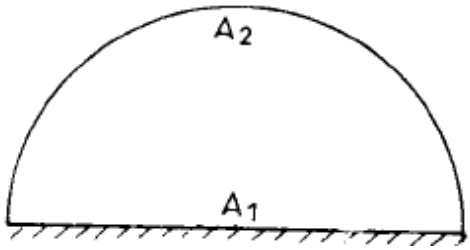
Shape factor F_A = 1

$$Q = 5.67 \times 10^{-8} \times 1 \times \frac{12}{23}\left(800^4 - 500^4\right) = 1026 W/m^2 = 10.26 kW/m^2$$

37. A long semi-circular dud is shown in the given figure. What is the shape factor F_{22} for this case?

(a) 1.36

(c) 0.56

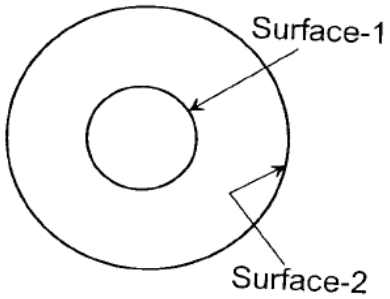


[IES-1994]

37. Ans. (d) Shape factor $F_{22} = 1 - \frac{A_1}{A_2} = 1 - \frac{2rl}{\pi rl} = 0.36$

38. A hollow encloser is formed between two infinitely long concentric cylinders of radii 1 m ans 2 m, respectively. Radiative heat exchange takes place between the inner surface

of the larger cylinder (surface-2) and the outer surface of the smaller cylinder (surface-I). The radiating surfaces are diffuse and the medium in the enclosure is non-participating. The fraction of the thermal radiation leaving the larger surface and striking itself is **[GATE-2008]**

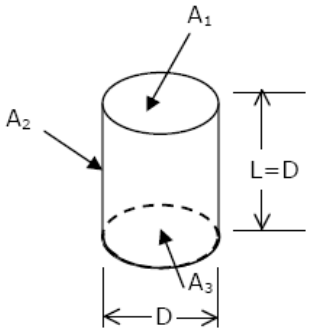


(A) 0.25 (B) 0.5 (C) 0.75 (D) 1

38. Ans. (B) It is shape factor= $1-\frac{A_1}{A_2}=1-\frac{\pi D_1 L}{\pi D_2 L}$

$=1-\frac{1}{2}=0.5$

39. For the circular tube of equal length and diameter shown below, the view factor F_{13} is 0.17.
The view factor F_{12} in this case will be
(a) 0.17 (b) 0.21
(c) 0.79 (d) 0.83



[GATE-2001]

39. Ans. (d)

Principal of conservation gives

$F_{1-1}+F_{1-2}+F_{1-3}=1$

$F_{1-1}=0$, flat surface cannot see itself

$\therefore 0+F_{1-2}+0.17=1$

or $F_{1-2}=0.83$

40. What is the value of the view factor for two inclined flat plates having common edge of equal width, and with an angle of 20 degrees? **[GATE-2002]**
(a) 0.83 (b) 1.17 (c) 0.66 (d) 1.34
40. Ans. (c)

41. Fraction of radiative energy leaving one surface that strikes the other surface is called
(a) Radiative flux (b) Emissive power of the first surface
(c) View factor (d) Re-radiation flux **[IES-2003]**
41. Ans. (c)

42. Match List I with II and select the correct answer using the code given below the Lists:

List I	List II
A. Heat Exchangers	1. View factor
B. Turbulent flow	2. Effectiveness
C. Free convention	3. Nusselt number
D. Radiation heat transfer	4. Eddy diffusivity

Code: **[IES 2007]**

	A	B	C	D		A	B	C	D
(a)	3	1	2	4	(b)	2	4	3	1
(c)	3	4	2	1	(d)	2	1	3	4

42. Ans. (b)

43. Match List - I with List - II and select the correct answer using the code given below the Lists:

List-I	List-II
A. Radiation heat transfer	1.Biot's number
B. Conduction heat transfer	2. View factor
C. Forced convection	3. Fourier's law
D. Transient heat flow	4. Stanton number

[IES-2006]

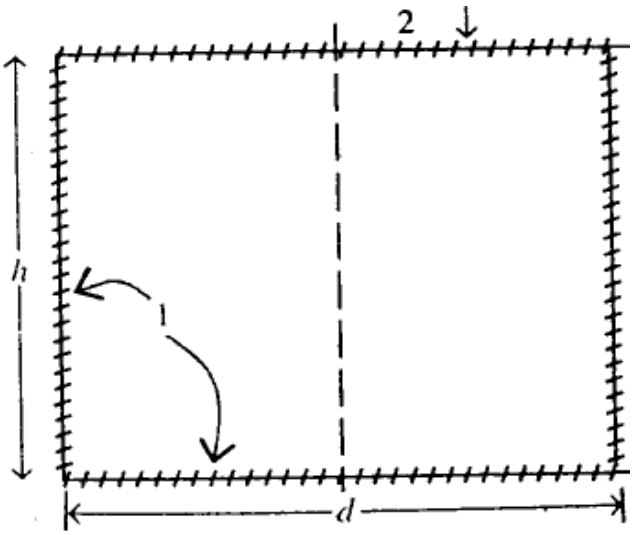
	A	B	C	D		A	B	C	D
(a)	4	3	2	1	(b)	2	1	4	3
(c)	4	1	2	3	(d)	2	3	4	1

43. Ans. (d)

44. What is the value of the shape factor F_{12} in a cylindrical cavity of diameter d and height h between bottom face known as surface 1 and top flat surface know as surface 2?

(a) $\dfrac{2h}{2h+d}$

(c) $\dfrac{4d}{4d+h}$



[IES-2004]

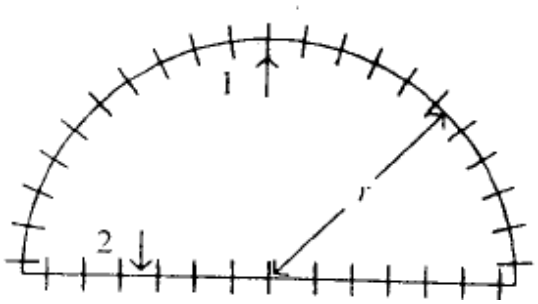
44. Ans. (b) $F_{2-2} = 0, \ \therefore F_{2-1} = 1$

$$A_1F_{1-2} = A_2F_{2-1} \quad \text{or } F_{12} = \frac{A_2}{A_1} = \frac{\pi d^2/4}{\frac{\pi d^2}{4} + \pi Dh} = \frac{d}{d+4h}$$

45. A hemispherical surface 1 lies over a horizontal plane surface 2 such that convex portion of the hemisphere is facing sky. What is the value of the geometrical shape factor F_{12}?

(a) ¼ (b) ½

(c) 3/4 (d) 1/8



[IES-2004]

45. Ans. (b) $F_{22} = 0 \quad \therefore F_{21} = 1$

$$A_1F_{12} = A_2F_{21} \qquad \text{or} \qquad F_{12} = \frac{A_2}{A_1} = \frac{\pi r^2}{2\pi r^2} = \frac{1}{2}$$

46. A solid cylinder (surface 2) is located at the centre of a hollow sphere (surface 1). The diameter of the sphere is 1 m, while the cylinder has a diameter and length of 0.5 m each. The radiation configuration factor F_{11} is **[GATE-2005]**

(a) 0.375 (b) 0.625 (c) 0.75 (d) 1

46. Ans. (c)

$F_{2-2} = 0;\ F_{2-1} = 1$

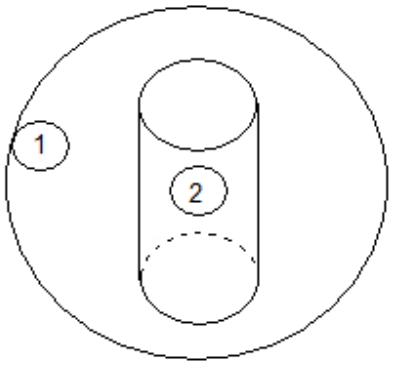
and $A_1F_{1-2} = A_2F_{2-1}$ or $F_{1-2} = \dfrac{A_2}{A_1}$

and $F_{1-1} + F_{1-2} = 1$ gives

$$F_{1-1} = 1 - F_{1-2} = 1 - \frac{A_2}{A_1} = 1 - \frac{\left(\pi DL + 2 \times \pi D^2/4\right)}{4\pi r^2}$$

[and given $D = L$]

$$F_{1-1} = 1 - \frac{1.5 \times 0.5^2}{4 \times 0.5^2} = 0.625$$



47. The shape factor of a hemispherical body placed on a flat surface with respect to itself is

(a) zero (b) 0.25 (c) 0.5 (d) 1.0 **[IES-2001]**

47. Ans. (d)

48. An enclosure consists of the four surfaces 1, 2, 3 and 4. The view factors for radiation heat transfer (where the subscripts 1, 2, 3, 4 refer to the respective surfaces) are F_{11} = 0.1, F_{12} = 0.4 and F_{13} = 0.25. The surface areas A_1 and A_4 are 4 m^2 and 2 m^2 respectively. The view factor F_{41} is **[IES-2001]**

(a) 0.75 (b) 0.50 (c) 0.25 (d) 0.10

48. Ans. (c)

49. The shape factors with themselves of two infinity long black body concentric cylinders with a diameter ratio of 3 are…… for the inner and…… for the outer. **[GATE-1994]**

49. Ans. 1, 1/9

Heat Exchange between Non-black Bodies, 661

50. Match List I (Surface with Orientations) with List II (Equivalent Emissivity) and select the correct answer: **[IES-2004]**

List I	List II
A. Infinite parallel planes	1. ε_1
B. Body 1 completely enclosed by body 2 but body 1 is very small	2. $\dfrac{1}{\dfrac{1}{\varepsilon_1}+\dfrac{1}{\varepsilon_2}-1}$
C. Radiation exchange Between two small grey bodies	3. $\dfrac{1}{\dfrac{1}{\varepsilon_1}+\left(\dfrac{A_1}{A_2}\right)\left(\dfrac{1}{\varepsilon_2}-1\right)}$
D. Two concentric cylinders with large lengths	4. $\varepsilon_1\varepsilon_2$

	A	B	C	D		A	B	C	D
(a)	3	1	4	2	(b)	2	4	1	3
(c)	2	1	4	3	(d)	3	4	1	2

50. Ans. (c)

51. Match List I with List II and select the correct answer using the codes given below the lists: **[IES-1995]**

List I	List II
A. Infinite parallel planes	1. ε_1
B. Completely enclosed body large compared to enclosing body (Subscript I for enclosed body)	2. $\varepsilon_1\varepsilon_2$
C. Two rectangles with common side perpendicular to each other.	3. $\dfrac{1}{\dfrac{1}{\varepsilon_1}+\dfrac{1}{\varepsilon_2}-1}$
D. Concentric cylinder	4. $\dfrac{-1}{\dfrac{1}{\varepsilon_1}+\dfrac{A_1}{A_2}\left(\dfrac{1}{\varepsilon_2}-1\right)}$

Code:	A	B	C	D		A	B	C	D
(a)	1	2	4	3	(b)	3	1	4	2
(c)	2	1	3	4	(d)	3	1	2	4

51. Ans. (d)

52. The radiative heat transfer rate per unit area (W/m^2) between two plane parallel grey surfaces (emissivity = 0.9) maintained at 400 K and 300 K is **[GATE-1993]**

(a) 992 (b) 812 (c)464 (d)567

(Stefan Boltzman constant. σ = 5.67 x 10-8 W/m^2K^4)

52. Ans. (b)

$$f_{12} = \frac{1}{\left(\frac{1}{\epsilon_1}+\frac{1}{\epsilon_2}-1\right)} = \frac{1}{\left(\frac{1}{0.9}+\frac{1}{0.9}-1\right)} = 0.818$$

$$Q = c\sigma (T_1^4 - T_2^4)$$
$$= 0.818 \times 5.67 \times 10^{-8} (400^4 - 300^4) = \mathbf{812\ W}$$

53. Two large parallel grey plates with a small gap, exchange radiation at the rate of 1000 W/m^2 when their emissivities are 0.5 each. By coating one plate, its emissivity is reduced to 0.25. Temperature remains unchanged. The new rate of heat exchange shall become **[IES-2002]**

(a) 500 W/m^2 (b) 600 W/m^2 (c) 700 W/m^2 (d) 800 W/m^2

53. Ans. (b)

54. For the radiation between two infinite parallel planes of emissivity ε_1 and ε_2 respectively, which one of the following is the expression for emissivity factor?

(a) $\varepsilon_1 \varepsilon_2$ (b) $\frac{1}{\varepsilon_1} + \frac{1}{\varepsilon_2}$

(c) $\frac{1}{\frac{1}{\varepsilon_1} + \frac{1}{\varepsilon_2}}$ (d) $\frac{1}{\frac{1}{\varepsilon_1} + \frac{1}{\varepsilon_2} - 1}$ **[IES 2007]**

54. Ans. (d)

55. For infinite parallel planes with emissivities ε_1 and ε_2 the interchange factor for radiation from surface 1 to surface 2 is given by **[IES-1993]**

(a) $\frac{\varepsilon_1\varepsilon_2}{\varepsilon_1+\varepsilon_2-\varepsilon_1\varepsilon_2}$ (b) $\frac{1}{\varepsilon_1}+\frac{1}{\varepsilon_2}$ (c) $\varepsilon_1+\varepsilon_2$ (d) $\varepsilon_1\varepsilon_2$

55. Ans. (a)

56. A plate having 10 cm^2 area each side is hanging in the middle of a room of 100 m^2 total surface area. The plate temperature and emissivity are respectively 800 K and 0.6. The temperature and emissivity values for the surfaces of the room are 300 K and 0.3 respectively. Boltzmann's constant σ = 5.67 x 10-8 W/m^2 K^4. The total heat loss from the two surfaces of the plate is **[GATE-2003]**

(a) 13.66 W (b) 27.32 W (c) 27.87 W (d) 13.66 MW

56. Ans. (b) Given:

$A_1 = 2\times10\,cm^2 = 2\times10^{-3}m^2$ $A_2 = 100\,m^2$

$T_1 = 800K$ $T_2 = 300K$

$\varepsilon_1 = 0.6$ $\varepsilon_2 = 0.3$

Interchange factor $(f_{1-2}) = \frac{1}{\frac{1}{\varepsilon_1}+\frac{A_1}{A_2}\left(\frac{1}{\varepsilon_2}-1\right)} = \frac{1}{\frac{1}{0.6}+\frac{2\times10^{-3}}{100}\left(\frac{1}{0.3}-1\right)} = 0.6$

$$Q_{net} = f_{1-2}\sigma A_1\left(T_1^4 - T_2^4\right) = 0.6\times5.67\times10^{-8}\times2\times10^{-3}\left(800^4 - 300^4\right)W = 27.32\,W$$

57. Using thermal-electrical analogy in heat transfer, match List I (Electrical quantities) with List II (Thermal quantities) and select the correct answer: **[IES-2002]**

List I	List II
A. Voltage	1. Thermal resistance
B. Current	2. Thermal capacity
C. Resistance	3. Heat flow
D. Capacitance	4. Temperature

	A	B	C	D		A	B	C	D
(a)	2	3	1	4	(b)	4	1	3	2
(c)	2	1	3	4	(d)	4	3	1	2

57. Ans. (d)

58 For an opaque plane surface the irradiation, radiosity and emissive power are respectively 20, 12 and 10 W/m^2.What is the emissivity of the surface? **[IES-2004]**

(a) 02 (b) 0.4 (c) 0.8 (d) 1.0

58. Ans. (c) $J = \varepsilon E_b + (1-\varepsilon)G$

$12 = \varepsilon \times 10 + (1-\varepsilon) \times 20$ or $\varepsilon = 0.8$

59. Heat transfer by radiation between two grey bodies of emissivity ε is proportional to (notations have their usual meanings) **[IES-2000]**

$(a)\dfrac{(E_b - J)}{(1-\varepsilon)}$ $(b)\dfrac{(E_b - J)}{(1-\varepsilon)/\varepsilon}$ $(c)\dfrac{(E_b - J)}{(1-\varepsilon)^2}$ $(d)\dfrac{(E_b - J)}{(1-\varepsilon^2)}$

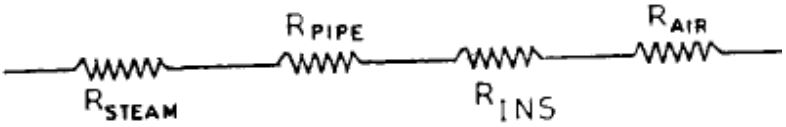
59. Ans. (*)

60. Solar radiation of 1200 W/m^2 falls perpendicularly on a grey opaque surface of emissivity 0.5. If the surface temperature is 50°C and surface emissive power 600 W/m^2, the radiosity of that surface will be **[IES-2000]**

(a) 600 W/m^2 (b) 1000 W/m^2 (c) 1200 W/m^2 (d) 1800 W/m^2

60. Ans. (c)

61. A pipe carrying saturated steam is covered with a layer of insulation and exposed to ambient air.



The thermal resistances are as shown in the figure.

Which one of the following statements is correct in this regard? **[IES-1996]**

(a) R_{sream} and R_{pipe} are negligible as compared to R_{ins} and R_{air}

(b) R_{pipe} and R_{air} are negligible as compared to R_{ins} and R_{steam}

(c) R_{steam} and R_{air} are negligible as compared to R_{pipe} and R_{ins}

(d) No quantitative data is provided, therefore no comparison is possible.

61. Ans. (a) The resistance due to steam film and pipe material are negligible in comparison to resistance of insulation material and resistance due to air film.

62. Which of the following would lead to a reduction in thermal resistance?

1. In conduction; reduction in the thickness of the material and an increase in the thermal conductivity. **[IES-1994]**
2. In convection, stirring of the fluid and cleaning the heating surface.
3. In radiation, increasing the temperature and reducing the emissivity.

Codes:

(a) 1, 2 and 3 (b) 1 and 2 (c) 1 and 3 (d) 2 and 3

62. Ans. (b) 1. In conduction, heat resistance = $\Delta x / kA$

Thus reduction in thickness and increase in area result in reduction of thermal resistance.

2. Stirring of fluid and cleaning the heating surface increases value of h, and thus reduces thermal resistance.

3. In radiation, heat flow increases with increase in temperature and reduces with reduction in emissivity. Thus thermal resistance does not decrease. Thus 1 and 2 are correct.

Radiation Shields, 692

63. Two long parallel surfaces, each of emissivity 0.7 are maintained at different temperatures and accordingly have radiation exchange between them. It is desired to reduce 75% of this radiant heat transfer by inserting thin parallel shields of equal emissivity (0.7) on both sides. What would be the number of shields? **[IES-2004]**

(a) 1 (b) 2 (c) 3 (d) 4

63. Ans. (c) $\frac{Q_{\text{withinshield}}}{Q_{\text{without shield}}} = \frac{1}{n+1}$ or $0.25 = \frac{1}{n+1}$ or $n = 3$

64. Two long parallel plates of same emissivity 0.5 are maintained at different temperatures and have radiation heat exchange between them. The radiation shield of emissivity 0.25 placed in the middle will reduce radiation heat exchange to **[IES-2002]**

(a) 1/2 (b) 1/4 (c) 3/10 (d) 3/5

64. Ans. (c)

65. Two long parallel surfaces each of emissivity 0.7 are maintained at different temperatures and accordingly have radiation heat exchange between them. It is desired to reduce 75% of this radiant heat transfer by inserting thin parallel shields of emissivity on both sides. The number of shields should be **[IES-1992]**

(a) one (b) two (c) three (d) four

65. Ans. (c)

58. Let N be the required number of shields. When emissivities of the main radiating surfaces and those of parallel radiation shields are equal, then $\frac{\text{Without shields}}{\text{with shields}} = \frac{1}{N+1}$

Given, $Q_{\text{shielded}} = (1 - 0.75)\, Q_{\text{unshielded}}$

$\therefore \quad \frac{1}{(N+1)} = 0.25$

or $N = 3.$

Answers with Explanation (Objective)

8. Mass Transfer

Objective Questions (IES, IAS, GATE)

Modes of Mass Transfer. 715

1. If heat and mass transfer take place simultaneously, the ratio of heat transfer coefficient to the mass transfer coefficient is a function of the ratio of **[IES-2000]**
(a) Schmidt and Reynolds numbers (b) Schmidt and Prandtl numbers
(c) Nusselt and Lewis numbers (d) Reynolds and Lewis numbers
1. Ans. (a)

2. In case of liquids, what is the binary diffusion coefficient proportional to?
(a) Pressure only (b) Temperature only **[IES-2006]**
(c) Volume only (d) All the above
2. Ans. (d)

3. In a mass transfer process of diffusion of hot smoke in cold air in a power plant, the temperature profile and the concentration profile will become identical when: **[IES-2005]**
(a) Prandtl No. = 1 (b) Nusselt No. = 1 (c) Lewis No. = 1 (d) Schmilt No. = 1
3. Ans. (d)

Fick's Law, 718 .

Answers with Explanation (Objective)